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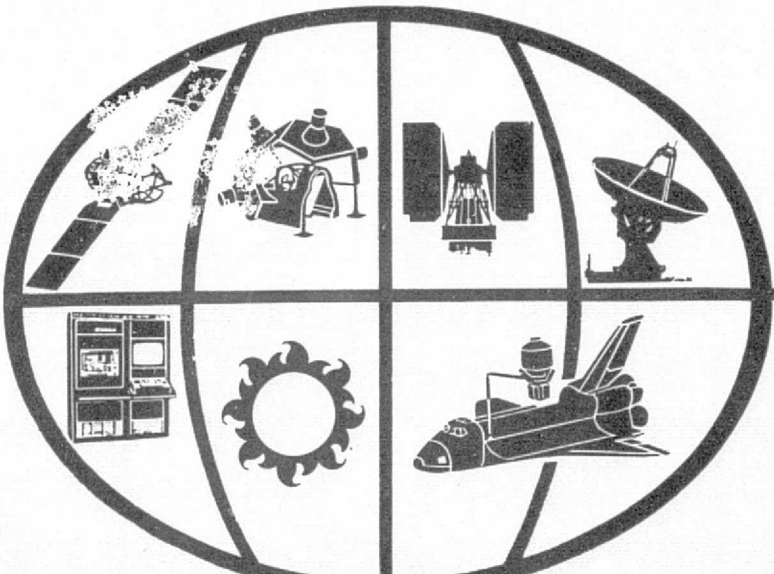
LANDSAT D

DATA TRANSMISSION AND DISSEMINATION STUDY

FINAL REPORT

Prepared for
THE NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
GODDARD SPACE FLIGHT CENTER
GREENBELT, MARYLAND 20771



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SECTION 1

INTRODUCTION AND SUMMARY

1.1 BACKGROUND

The pressing need to better survey and manage the earth's resources and environment has prompted man to explore the possibilities of remote sensing from space. Early efforts began with space photographs from the Gemini and Apollo programs and continued with multispectral data from Landsat 1 and 2 spacecraft. Landsat D is currently planned as the next major step for the Earth Resources Program.

Landsat 1, launched in 1972, marked the start of NASA's Earth Resources satellite program. This successful spacecraft was followed two and a half years later with Landsat 2, an identical spacecraft. The overwhelming success of these two Landsats, demonstrated through hundreds of experimental programs, has motivated NASA to continue to improve the Earth Resources satellite program. The third satellite, Landsat C, has been procured and is scheduled for launch in late 1977. This third satellite will carry a modified Multispectral Scanner and will utilize an improved digital ground system. NASA is now planning for the next step, Landsat D, which will provide several major advances. Landsat D will incorporate the Thematic Mapper (TM) as a new sensor, it will utilize the Multi-mission Modular Spacecraft (MMS), it will make use of the Tracking and Data Relay Satellite System (TDRSS) and it will employ a new more advanced ground system. Each of these represent significant improvements in the state-of-the-art. This study is one of several which address various aspects of the planned Landsat D system.

As the Earth Resources Program has matured through the Landsat spacecraft it has begun the transition from an experimental research activity to a sound demonstration of proven utility. This important transition will be completed with the Landsat D system which incorporates several key improvements over the current system. These improvements, based on experience with the existing Landsats, will provide new capabilities in the spacecraft, the sensor, the ground system, and the overall system design. These system

capabilities - which emphasize improved vegetation analysis, prompt availability of data, frequent coverage, and precise data registration and overlay for better change detection will permit the Landsat D to capture already proven economic benefits in such diverse applications as:

- Monitoring world-wide food productivity
- Mapping agricultural land use
- Monitoring rangelands
- Surveying forest resources
- Managing critical watersheds
- Detecting land use changes
- Oil/mineral exploration

An artist's concept of the Landsat D system is shown in Figure 1-1. The spacecraft will be based on NASA's new Multi-mission Modular Spacecraft (MMS) and will operate two remote sensing instruments: a Thematic Mapper (TM), with 30 meter ground resolution, and a Multispectral Scanner (MSS), with 80 meter resolution. The system provides two data communication paths to the Earth; one is a direct readout link for ground stations (both

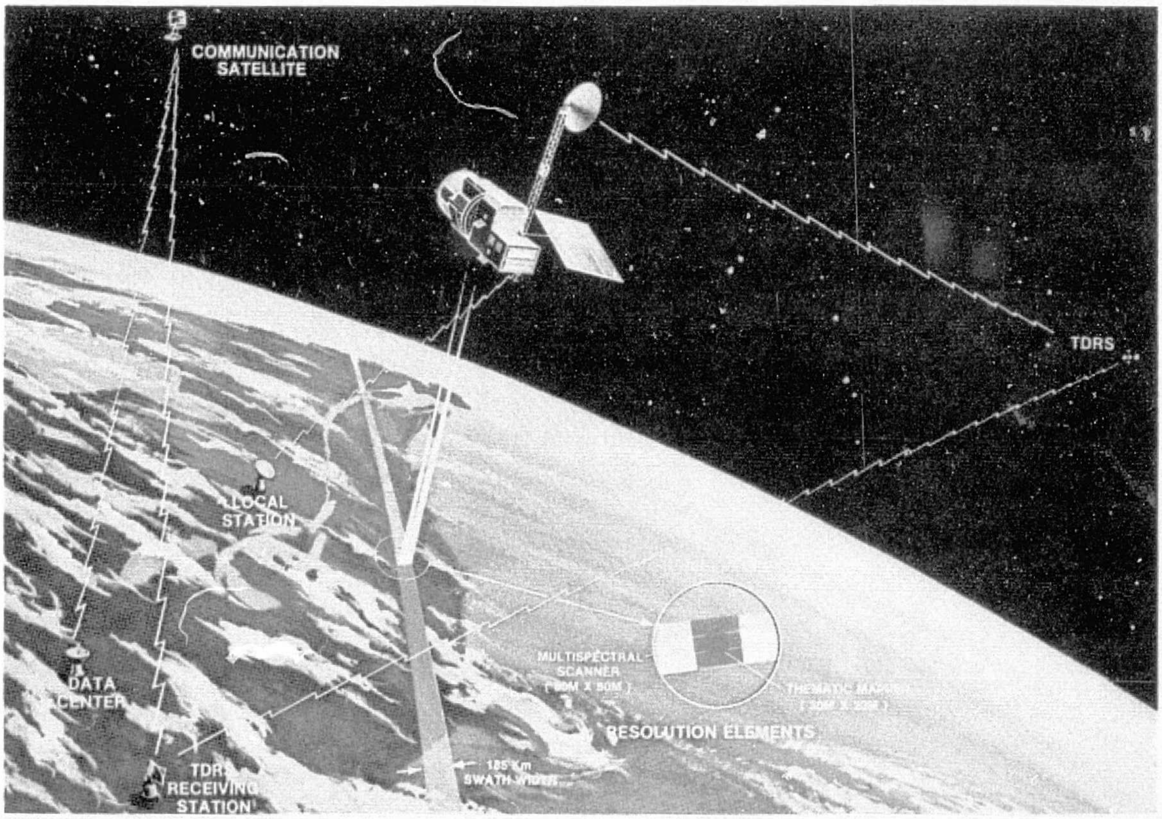


Figure 1-1. Landsat D System

domestic and foreign) within range of the spacecraft, and the other is a relay link via the Tracking and Data Relay Satellite System (TDRSS) for nearly full global coverage. The spacecraft will be in a sun-synchronous orbit with a descending node time of 9:30 AM (similar to current Landsats). The orbital altitude and inclination will provide near global coverage of the land and near coastal regions with a repeat cycle every 16 to 18 days.

The use of the new MMS spacecraft as the basic bus will provide both improved sensor pointing accuracy (±0.01 degree) and stability (10^{-6} degrees/second). These improvements will manifest themselves in more accurate and more straightforward geometric corrections of the image data; both relative (image to image) and absolute (with respect to the Earth's surface). The MMS incorporates modular subsystems in the key areas of power, attitude control, and command and data handling. This modularity together with the compatibility for both conventional and Space Shuttle launches will enable in-orbit repair and refurbishment of the spacecraft.

The Thematic Mapper, TM, is an evolutionary improvement of the MSS and provides several significant capabilities. The spatial resolution on the ground has been reduced to 30 meters (compared to 80 for the MSS which will allow radiances to be measured for areas (pixels) less than one sixth the size as for the MSS. The TM will incorporate six spectral bands (and have the capability for a seventh) which have been located primarily on the basis of their ability to discriminate vegetation (a fundamental application of remote sensing). In addition the radiometric sensitivity of the TM has been improved by reducing the signal-to-noise characteristic and increasing the levels of digital quantization. These sensor changes combine to cause the TM to have a data rate of 120 Mbps, (an order of magnitude increase over the 15 Mbps of the MSS).

For remotely sensed multispectral data to be truly practical for many potential operational users (agricultural analysts, hydrologists, etc.) it must be received by them in usable form within 48 to 96 hours after imaging. Promptness in receiving data products is one of the most critical aspects of the Landsat System.

The Landsat D System will be thoroughly integrated with the needs of operational users. It will include improved preprocessing of all data, central data processing, archiving and retrieval,

low-cost receiving and data centers for large volume users (such as the U.S. Department of Agriculture) and provide maximum efficiency and economy in utilization by state, regional, and foreign users. Featuring the rapid electronic transmission of all data, the Landsat D system will reduce the time between satellite imaging and user reception of data to the required 48 to 96 hours.

As illustrated in the artist's concept the system provides two data links to the ground. The first link, for both MSS and Thematic Mapper data, is directly from the satellite to domestic and foreign ground stations as the satellite passes through their reception areas. The second link is via the Tracking and Data Relay Satellite System (TDRSS). As shown, the data is transmitted to a TDRSS satellite, in stationary orbit, and relayed to the TDRSS receiving station. The TDRSS receiving station transmits the data via a domestic communications satellite to a central data processing facility that, in turn, relays the data to any local data distribution center equipped to receive it. This link, via TDRSS and the communications satellite, will thus have global acquisition and relay capabilities, providing rapid access to Thematic Mapper data for users throughout the world. Both data links have a planned maximum data capability of 135 Mb/second at a 10^{-5} bit error rate.

The Landsat D system described is currently in the planning stages by NASA. As part of the planning for this future system, NASA has undertaken a series of studies, with General Electric and others, to investigate various system options. This particular study is one of seven conducted by General Electric to explore different aspects of the total ground system that will be required by Landsat D in order to meet the overall mission objectives.

The seven ground system studies are:

1. Local User Terminal Study - an investigation into the requirements and options available for direct readout (primarily foreign ground stations) of Landsat D data.

2. User Data Processing Study - an effort to estimate the scope, size, and cost of the major user data processing system requirements.

3. Data Processing Facility Study - a requirement and sizing study to provide preliminary estimates of the scope and cost of NASA's central Landsat D data processing center.

4. GSFC Research & Development Study - a survey and analysis of the functions and facility required of NASA to continue the basic research on spaceborne remote sensing and its applications.

5. Operation Control Study - an analysis of the modifications necessary to upgrade or modify the NASA Operations Control Center (OCC) for Landsat D.

6. Data Transmission and Dissemination Study - an investigation into the options and limitations of various data communication alternatives including centralization versus decentralization.

7. Position Determination and Correction Study - an analysis of the impact and alternatives afforded by the MMS spacecraft of Landsat D on image geometric correction.

1.2 THE LANDSAT D GROUND SYSTEM

A top-level functional diagram of the Landsat D ground system is presented in Figure 1-2. The five major subsystems included are the Data Input Subsystem (DIS), the Central Data Processing Facility (CDPF), the Product Generation and Dissemination Facility (PGDF), the Data Management Subsystem (DMS), and the Agriculture Utilization Subsystem (AUS). Each of these subsystems is briefly described below.

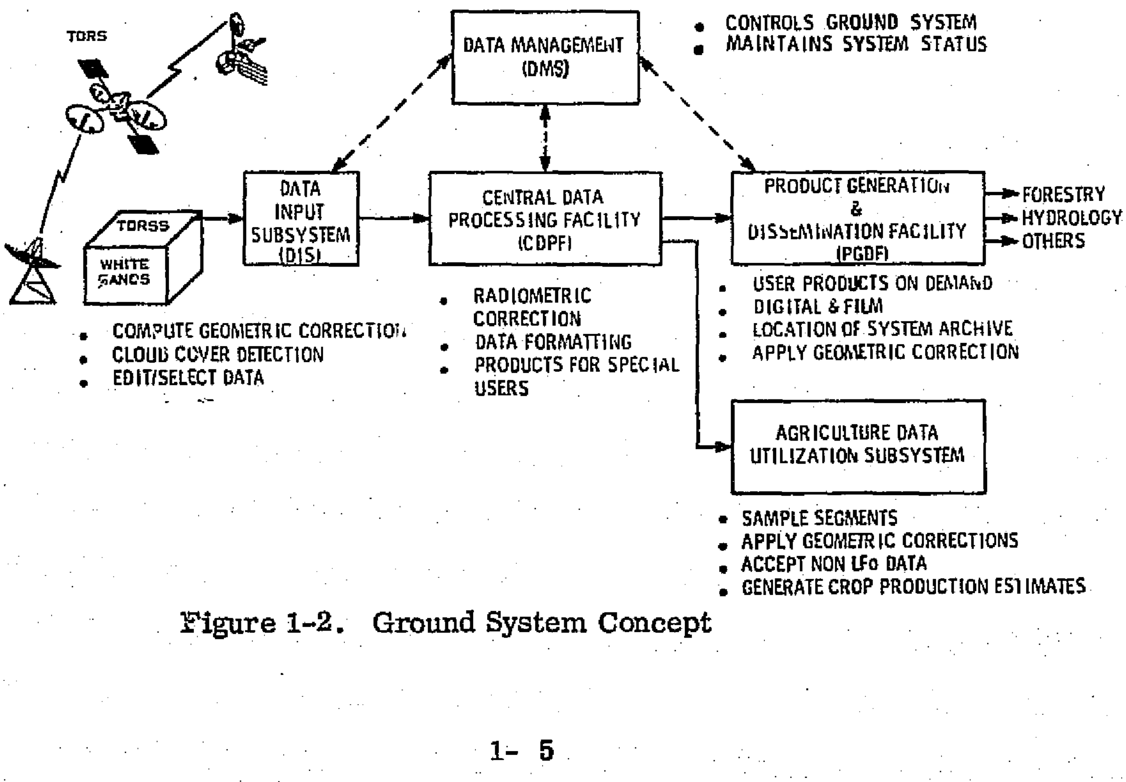


Figure 1-2. Ground System Concept

The Data Input Subsystem (DIS) receives 120-135 Mbps data from the TDRSS via dedicated cable interconnection. The prime functions of the DIS are to record the raw input data, to perform cloud cover detection and scene editing, and to compute geometric correction matrices on a per swath basis.

The Central Data Processing Facility (CDPF) receives edited data from the DIS and performs standard operations to all data. These operations include radiometric correction and data reformatting to a band-interleaved-by-line (BIL) format.

The Product Generation and Dissemination Facility (PGDF) is the main interface between the Landsat D ground system and general users. This facility provides Landsat D data, in either digital tape or film format, to users on demand. The data, which may be geometrically corrected to various map projection systems or enhanced as requested by the user, is available in a variety of sizes, formats, and media. The PGDF also houses and manages the system archive.

The Data Management Subsystem (DMS) provides the central point of control and data base management for the Landsat D ground system. Its prime functions include management of user demand, the system archive, system communications, and system redundancy. The DMS also maintains system status, production statistics, operations logs and administrative services.

The Agriculture Utilization Subsystem (AUS) receives data directly from the CDPF and performs those operations necessary to produce world crop production forecasts on a periodic basis. The operations to be performed include geometric correction, sample segment extraction, multispectral analysis, and areal and statistical analyses. It is included here as part of the ground system because it represents the first major user of Landsat D data.

Several other major subsystems included as part of the Landsat D ground system were considered. These include the Operations Control Center (OCC), the GSFC Research and Development Facility, and the Hydrologic Land-Use Utilization Subsystem. The OCC performs the functions required to plan, schedule, operate and evaluate spacecraft and payload

operations. The R&D Facility enables NASA to perform research related to the Landsat program and its applications. The Hydrologic/Land Use Utilization Subsystem is similar in concept to the AUS and will generate land use maps over watershed areas within the US.

1.3 SUMMARY

The Landsat D vehicle's prime sensor, the Thematic Mapper, will have a data rate of approximately 120 Mbps (an order of magnitude greater than current Landsat vehicles). This higher data rate creates new problems in data handling, many of which must be solved by the ground system. The Landsat D mission will employ several new technology systems in its data transmission and dissemination systems. Since there will be no tape recorders on board the spacecraft, the only methods of retrieving Thematic Mapper and Multispectral Scanner data will be via direct readout to ground stations or via the Tracking and Data Relay Satellite System (TDRSS). This study examines several aspects of the problem of transferring data from the TDRSS ground station at White Sands, New Mexico, through the necessary ground processing centers and to the user.

An assessment of the quantity of data which must be processed by the system is contained in Section 2 (System Loading Analysis). This includes estimates of the vehicle data output rate and data requirements for various missions. A strategy for reducing the quantity of data (number of scenes) to be processed on a daily basis is developed and proposed. This scene reduction strategy, based on satisfying all of the mission requirements, results in a system processing load of 438 scenes or 10^{12} bits per day.

Section 3 (Data Transmission Methods) examines the various candidate methods for data transmission within the system. These methods, including satellite, terrestrial, and hard copy transmission, are evaluated as a function of capacity, availability, cost, reliability, time delay, etc.

Various methods of temporary and permanent data storage were considered during the study. Section 4 (Archive Organization and Costs) examines the archival requirements of the system, the potential storage media, and the supporting equipment required for each of these options.

Section 5 (Site Selection) examines the effect of the location of various portions of the ground processing system on the total system. It evaluates each of the currently feasible sites for each ground processing function with regard to cost and function related criteria. The conclusion, that the entire ground processing system should be located in White Sands, New Mexico is fully developed and explained.

SECTION 2

SYSTEM LOADING ANALYSIS

The first portion of this section develops the data parameters associated with one Landsat scene. The second portion evaluates the various state-of-the-art methods of cloud cover detection. This data is used in the third portion of this section, which actually analyzes the impact of cloud cover editing on system loading.

2.1 DERIVATION OF STUDY PARAMETERS

In order to realistically compare the cost and time delays associated with the various data transmission options, it is necessary to determine the quantities of data involved. The following Thematic Mapper characteristics were assumed for purposes of estimation:

Scene size:	185 km X 185 km
Instantaneous Field of View (IFOV):	30 meters X 30 meters
Effective No. of Bands Data:	5.06*
Bits per Spectral Value:	8
Sampling in Scan Direction:	1.0 samples/IFOV

1. 185 km X 185 km = 34,225 km^2/scene
2. $\dfrac{34,225\ km^2/\text{scene}}{900\ m^2/\text{pixel}}$ = 38,027,777 pixels/scene
3. 38M pixels/scene X 5.06 spectral bands = 192.4 bytes/scene
4. 192.4M bytes/scene X 8 bits/byte = 1539M bits/scene
5. 1539M bits/scene X 1.0/scan over sample = 154G bits/scene
6. $\dfrac{1.54G\ \text{bits/scene}}{25\ \text{sec/scene}}$ = 61M bits/sec - data rate
7. $\dfrac{120\ \text{mB/s (data rate including cal. \& sync)}}{61\ \text{Mb/s (data rate)}}$ x 1.54G bits/scene = 3.0G bits/scene

* The TM can accumulate data in six distinct spectral bands. The IFOV of Bands 1-5 is 30m, while the IFOV of Band 6 (10.5-12.5μm) is 120m. The effective number of full bands of information is

$$\left(5 \text{ bands x } \frac{900\ m^2}{900\ m^2}\right) + \left(1 \text{ band x}\left(\frac{30\ m}{120m}\right)^2 \text{ x}\left(\frac{900\ m^2}{900\ m2}\right)\right) = 5.06$$

effective bands (data)

The data used for evaluating the Multispectral Scanner data is:

Scene Size:	185 X 185 km
Instantaneous Field of View (IFOV):	80 meters
Effective No. of Bands Data*:	4.11*
Bits/Spectral Value:	6
Sampling in Scan Direction:	1.4 samples/IFOV

1. 185 km X 185 km = 34,225 km^2/scene
2. $\frac{34,225 \text{ km}^2\text{/scene}}{6400 \text{ M}^2\text{/pixel}}$ = 5,347,656 pixels/scene
3. 5.347M pixels/scene X 1.4 oversample = 7.48M pixels/scene
4. 7.48M pixels/scene X 4.1 spectral bands = 30.7M bytes/scene
5. 30.7M bytes/scene X 6 bits/byte = 184.4M bits/scene
6. $\frac{184.4\text{M bits/scene}}{25 \text{ sec/scene}}$ = 7.37M bits/sec - data rate
7. $\frac{15 \text{ Mb/s (data rate incl. cal.\& sync)}}{7.37 \text{ bits/sec}}$ x 184.4M bits/scene = 375M bits/scene

* The multispectral scanner can accumulate data in 5 distinct spectral bands. Four of these bands have an IFOV of 80 meters, while one (band 5) has a 240m IFOV. The effective number of information bands are:

$$\left(4 \text{ bands X } \frac{6400 \text{ m}^2}{6400 \text{ m}^2}\right) + \left(1 \text{ band x } \left(\frac{80 \text{ m}}{240\text{m}}\right)^2 \text{ x } \left(\frac{6400 \text{ m}^2}{6400 \text{ m}^2}\right)\right) = 4.11 \text{ effective bands (data)}$$

3.2 CLOUD COVER DETECTION

Current estimates indicate that with two Landsat D spacecraft operating in a "wide open" mode, an average of 1768 scenes would be transmitted to the TDRSS ground station at White Sands daily (see Section 2.3 for loading analysis). Experience has shown that less than one-half of these scenes will contain usable, cloud-free information. The remainder will cover

areas of open ocean, regions of the world of little interest (such as Antarctica), or will be cloud covered. Predicted ephemeris will allow for deletion of the first two cases, but cloud cover editing will be required for the minimization of the third case. The cloud cover "filter" should be inserted as close to the "front end" of the system as possible. The GE system proposes that this filtering function be integrated into the Data Input Subsystem at White Sands.

Alternate methods of implementation of this cloud cover detector will also be evaluated in this section. Actual image data editing is addressed in section 2.3 (System Loading and Editing Criteria).

2.2.1 ALTERNATE DETECTION METHODS

Four methods of cloud cover detection were investigated. The first method, referred to as the Manual Approach, involves interpreter accept/reject decisions based on viewing either CRT or film displays of the data. The second method, the Weather Photo Approach, is a semi-automatic approach in which a visual interpretation of weather satellite photos is used to establish accept/reject decisions for Landsat data. The third method, the Digital Data Base Approach, is an automatic approach in which editing decisions are based on target signatures derived from previous cloud-free spectral data. The fourth method, the Digital Multispectral Approach, involves making instantaneous decisions based upon pre-established cloud signatures.

2.2.1.1 The Manual Approach

In this approach, each image is individually assessed by an interpreter. It is the method currently in use in the Landsat program. The visual inspection uses archival film, in 70 mm. positive roll form producing the Electron Beam Recorder. The image is divided into four quadrants and the cloud cover for each is subjectively assessed. The four values are averaged to arrive at a single cloud cover value for the scene. The data is entered onto cards and the main image file is updated.

Several methods of viewing the data were investigated. All would involve some kind of data reduction (36:1 to 144:1) so that a scene could be quickly displayed and its cloud cover assessed.

DICOMED Corporation was contacted for information concerning their hard copy and display output devices. They offer a 2000-line D-36 photochromic storage tube with a 2-minute write time, and 20-second erase time for about $27K. They also offer a 2000-line D-48 image film recorder priced at $100-125K, which, by 1980, will be able to expose an image in about 10-15 seconds. COMTAL Corporation was contacted concerning their 1000-line solid-state refresh display which will sell in 1980 for under $50K.

2.2.1.2 The Weather Photo Approach

This approach employs the same type of cloud cover editing as is currently used for sensor scheduling in the Landsat 1 and 2 programs. For these programs global cloud cover predictions are received on a daily basis for payload scheduling. These predictions are from 15-39 hours in advance and are tabulated in 3 categories of cloud cover: I - 0 to 30%, II - 40 to 70%, and III - 80 to 100%. Orbits are corrected with the predicted cloud cover and a priority evaluation procedure. The output of this procedure is a sensor utilization schedule which minimizes the cloud covered data accumulated during operations.

The proposed application of this system to the Landsat D program involves using actual (rather than predicted) cloud cover information to control cloud cover editing. Weather satellite photographs taken at the same time that the Landsat images are being acquired, would be used to make cloud cover editing decisions.

Several problems were immediately encountered concerning the feasibility of this application. The first problem deals with cirrus clouds, high-altitude clouds which are composed of narrowbands or patches of thin, fleecy parts. These clouds look more opaque to the weather satellites than to Landsat. The second problem is one of resolution. The NOAA-4 satellite has an Instantaneous Field of View (IFOV) of 2.0 nautical miles. The GOES satellite, a geostationary spacecraft, acquires the entire globe on each image. When contrasted with theThematic Mapper's (TM) expected IFOV of 30 meters, one finds an IFOV approximately 15,000 times smaller in area than the NOAA-4 satellite. This indicates that the scale of weather satellite data may be too small to quantify cloud cover for Landsat D imagery. As an example, the Weather Service may make a category II cloud cover

classification (40 - 70%) over a large area, but there may actually be 10% - 20% cloud-covered 185 X 185 km areas within that area designated Category II.

2.2.1.3 The Digital Data Base Approach

Two specific digital cloud cover detection systems were investigated: those operated by NOAA and the Air Force. The NOAA system involves operational cloud cover detection based on digital data from the Geostationary Operational Environmental Satellites (GOES). Using visible (.5 - .7 μm) and IR (10-12μm) data and an IFOV of approximately 6.9 X 6.0 km, cloud cover measurements are made for 100 km square cells (quantized to 5%). In this system, background information, a history of the spectral response of each grid cell, is employed to account for zenith angle, seasonal, and geographical variations.

The second operational system is the US Air Force Satellite Three Dimensional Nethanalysis system at Offutt Air Force Base. In the Air Force System both visible and IR data are combined with 7-day background data, on a 30 mi. by 30 mi. unit cell basis, to make a digital cloud cover determination. In this case, an extremely complex decision structure, based on visible and IR values, background information and data from a variety of other sources, is employed.

A scaling problem is encountered when these systems are fitted to the Landsat-D ground system's editing needs. Each system claims that it must use background information because of the similarity in spectral response of clouds, sand, snow and ice. The current data bases required for this background information are quite manageable because of the extremely large grid cell sizes employed. The Landsat D program, however, requires grid cell sizes that are much smaller and the data collection is so varied that the background data base would not be feasible.

2.2.1.4 The Digital Multispectral Approach

Recent work by several investigators has indicated that it is possible to reliably determine cloud cover digitally without background information. Based on experiments with SKYLAB S192 data, Barnes has indicated that it is possible to distinguish water clouds from snow cover using data from the 1.5-2.0 μm portion of the spectrum. He reports that in this band, snow reflectance drops off markedly while that of water clouds did not.

This finding was corroborated and extended by Curran of Goddard. Curran has indicated that using a visible channel, a near IR channel (1.55-1.75μm), and a thermal IR channel (all available from Thematic Mapper) it is possible to distinguish ice clouds, water droplet clouds and snow. He feels that some development work is required before an operational system can be created for Thematic Mapper data. Thresholds in each band would have to be determined from statistics and the Landsat proble.n of pixel saturation in bright clouds would have to be solved. However, these problems are modest ones and it is Curran's opinion that all digital cloud cover detection will be feasible by 1980.

2.2.2 SYSTEM EVALUATIONS

Several factors were considered in the system comparison. Among these are cost, accuracy, time delay and system resolution. A summary of the .· estigation is shown below:

	Manual Approach	Weather Photo Approach	Digital Data Base	Digital Multi-Spectral
Cost	2	3	-1	3
Accuracy	1	0	3	3
Time Delay	1	2	3	3
Resolution	2	0	2	3
Risk	3	3	2	2
Total Rating	9	8	10	14

Rating Key

0 = Unacceptable   1 = Poor   2 = Fair   3 = Good

The most important drawback of the Manual Approach is the inaccuracy and inconsistency of the subjective cloud cover evaluations. An additional disadvantage of this system is the time delay associated with the manual interpretation. Since viewing and interpretation cannot be performed in real-time, additional hardware will be required.

The disadvantages of the Weather Photo Approach are due to the resolution mismatch between the cloud cover assessment imagery and the Landsat D imagery. This leads to both inaccuracy

of cloud cover area assessment and cloud cover vs. non-cloud cover discrimination.

The overwhelming drawback of the digital data base system is the inordinately large data base that would have to be created and maintained.

The digital multispectral approach appears to be the preferred cloud cover detection method. Its one slight disadvantage is the fact that some development work is required to statistically determine the signatures of the critical "observables" in the spectral bands to be used. It is the opinion of several experts in the field, that this risk is a modest one.

2.2.3 CONCLUSIONS

The main development item for the cloud cover detection system is the establishment of appropriate cloud cover statistics and signatures. Since little data has been acquired in the 1.55 to 1.75 μm band in the past, a program of data acquisition and analysis must be undertaken. Specifically, the "tails" of the signatures must be well understood in order to achieve automatic classification independent of geographic area.

Detection and utilization of cloud cover data would be performed in a two-pass operation. As the raw image data initially enters the Data Input Subsystem, a real time assessment of a sampled subset of the data in each scene is performed. This requires division of the data into scenes, which can be accomplished using predicted ephemeris and time of acquisition. In addition, each scene is divided into 16 sectors (4 x 4 grid) for an automatic sectorized assessment of cloud cover. This data is extremely valuable to users interested in the cloud cover of a specific portion of a scene.

Cloud cover data will be utilized by the scene editor at the input to the CDPF. A hierarchy of priorities will be established, based on 12 hours of data, to accomplish the scene editing (see section 2.3).

2.3 SYSTEM LOADING AND EDITING CRITERIA

The use of the TDRSS allows the Landsat D system access to substantially more data than has been available from previous Landsat programs. All data (except for a TDRSS exclusion zone

over India) acquired by the Landsat spacecraft may be relayed to White Sands via the TDRSS System. For the purposes of this analysis, it is assumed that the spacecraft will be operated in the simplest mode possible (worst case) with one sensor "on" command and one sensor "off" command per pass. That is, the spacecraft will be turned on at the beginning (approximately 81°N) of the daylight portion of each orbital pass and not turned off until it has passed over the last land mass of the Southern Hemisphere prior to viewing Antarctica. Additional coverage outside of this area such as coverage of Antarctica and nightime coverage is discussed in Section 2.3.3.

This method of spacecraft operation leads to the acquisition of many "undesirable" scenes, such as those which are cloud-covered, or scenes which cover open ocean, and scenes which are not valuable. Using cloud cover information (obtained by means described in Section 2.2), predicted empheris and a probabilistic scene-sampling strategy, relatively undesirable (critieria to be defined) scenes can be identified for later editing. The sampling strategy is the final step in a data reduction procedure which is intended to satisfy the Landsat mission requirements for coverage acquisition while reducing the data load to a fixed reasonable size.

2.3.1 SUMMARY OF RESULTS

A summary of the overall system loading is shown in Figure 2-1. On the average, 1768 scenes/day (from 2 satellites) arrive at the Data Input Subsystem at White Sands. In practice less than that number will be recorded at the DIS by shutting off the tape recorders during periods when the Spacecraft is over open ocean. The number of scenes (approximately 1768) will be edited at the input to the Central Data Processing Facility (CDPF) to 438 scenes/day. All of these 438 scenes/day will be forwarded to the Product Generation and Dissemination Facility (PGDF) while 318 scenes/day (worst case coverage) will be sent to the Agricultural User.

Data requests to the PGDF, based on projections of current EROS data center volume, will be approximately 1400 image frames and 64 digital tapes daily.

The operation of the probabilistic editor is presented in Figure 2-2 and in Table 2-1. Of the 1768 scenes/day, approximately 1011 will contain land between 60°S and 70°N. In the highest

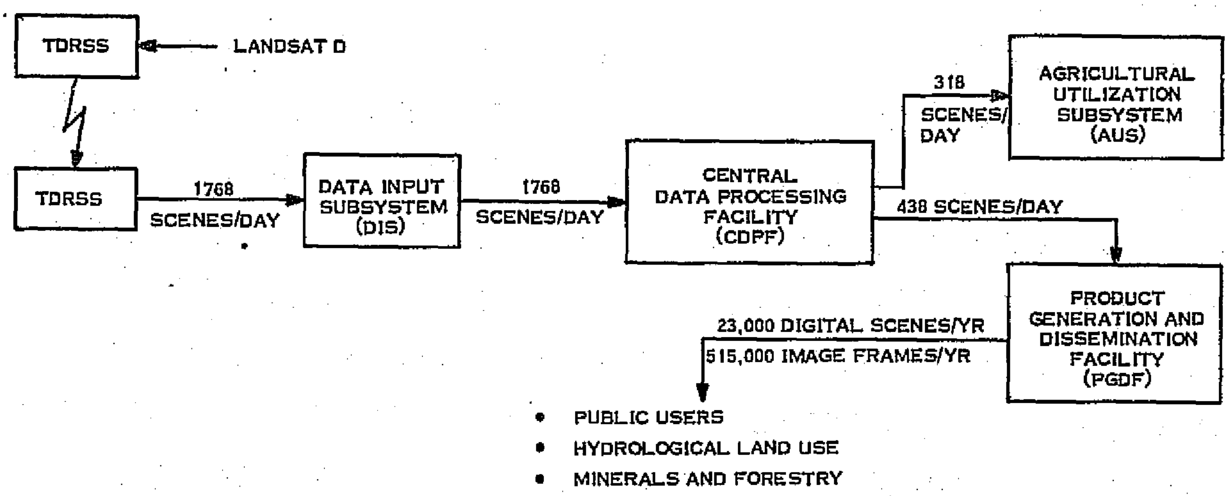


Figure 2-1. System Loading Diagram

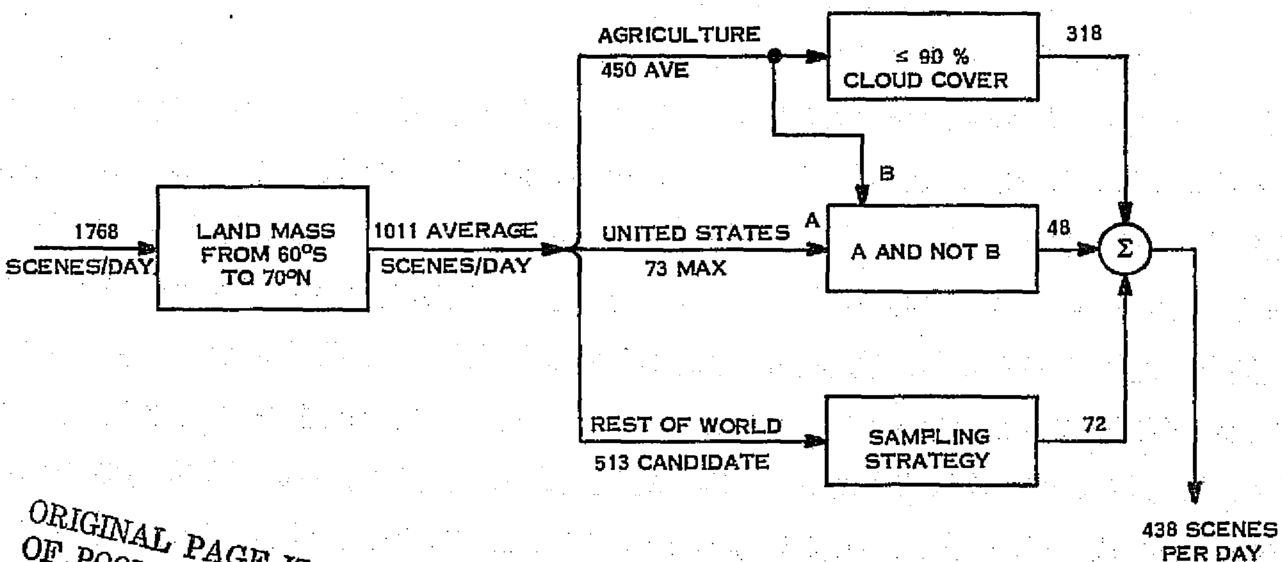


Figure 2-2. Probabilistic Editor Operation

Table 2-1. Editor Throughput

		2-SAT SYSTEM	1-SAT SYSTEM
(1)	Scenes/Day - Satellite ON/OFF 1/Pass	1768	884
(2)	$60^{o}S$ - $70^{o}N$ - Land Mass Only	1011	506
(3)	Global AG Scenes/Day Highest Activity Month	450	225
(4)	Global AG Scenes/Day ≤90% CC Avg. Worst Month	318	159
(5)	Max US Scenes not included in (3)	48	28
(6)	Candidate Rest of World Scenes [(2) - (3) - (5)]	513	253
	Most valuable scenes/pass (hardest to get) Sampling strategy to get the rest of the world once/quarter*	72	70
	Size of Pipeline: Agriculture	318	159
	U.S.	48	28
	Rest of World	72	70
		438	257

*The sampling strategy does not take adjacent scene overlap into account.

demand month, 450 of these scenes will be required daily for agricultural processing and of these 318 (average highest demand month) will have 90% cloud cover or less. The maximum number of US scenes/day not required by the agricultural mission will be 48. This leaves 513 candidate "rest-of-the-world" scenes per day. These scenes must be acquired only once per quarter. 72 "rest-of-the-world" scenes are selected daily for acquisition, thus making the fixed daily system load of (318 + 48 + 72) = 438 scenes/day.

2.3.2 INDIVIDUAL LINK ANALYSES

Three major drivers must be taken into account in a scene acquisition strategy. These are the agricultural mission, U.S. coverage, and the "rest-of-the-world". The agricultural mission consists of the production of worldwide inventory and yield forecast for six major crops. In order to accomplish this task, the agricultural mission requires acquisition of image data over designated crop areas every time the data is available. Coverage of the U.S. will also be obtained whenever it is available, for reasons of national interest, to support the hydrologic/land use mapping mission, and to support the forest inventory mission. Coverage of the rest of the world is defined as land areas from 60^{o}S to 70^{o}N which are not contained in the US scenes and which are not required by the agricultural mission that month. Coverage of the "rest of the world" is obtained on a quarterly basis (Note: This is more difficult than four times per year) and will support the minerals exploration mission and the general public. Each of these three drivers is factored into the definition and operation of the data editing function at White Sands. Meeting the needs of the first two drivers merely requires the acquisition of images whenever they are available. Satisfaction of the third driver's requirement calls for a more sophisticated approach. It is desirable to minimize the total number of scenes acquired each day while obtaining the "best" scenes available for that quarter. The results of these analyses will be a fixed size for the system "pipeline" based upon the mission requirements, operation of the Landsat D spacecraft, and the worldwide cloud cover probabilities.

2.3.2.1 Landsat D Spacecraft to TDRSS to White Sands Link

The first link in the processing chain to be analyzed is the spacecraft to ground link. This link carries all image data acquired by the spacecraft and is regarded as the starting point

of the Landsat ground processing system. Two methods of operating the spacecraft were assumed, resulting in two different loading profiles for the spacecraft to ground link. Method One: the operationally simpler method, involved turning the sensor on at the beginning of a descending pass and not turning it off until the spacecraft had passed the last land mass prior to viewing Antarctica. Method Two: which conserves power, involves turning the sensors on for the entire descending pass (including Antarctica) but turning the sensors off when the spacecraft sensor views a body of water for longer than ten scenes.

Method One, which would involve acquiring many scenes over open ocean and no scenes of Antarctica, can view 15,911 total global scenes per repeat cycle. This data was obtained by counting frame centers on U.S.G.S. - Edition 1 Landsat Coverage maps. All data assumes 2 spacecraft in interleaved orbits. The average number of scenes/day acquired when operating the spacecraft in Method One was 1768. A breakdown of the daily loading profiles for Method One and Method Two spacecraft operation is presented in Table 2-2.

Table 2-2. Scene Acquisition Loading Profile

	Method 1	Method 2
Day 1 (1 + 10)	1766	1588
Day 2 (3 + 12)	1741	1578
Day 3 (5 + 14)	1738	1676
Day 4 (7 + 16)	1806	1685
Day 5 (9 + 18)	1744	1637
Day 6 (11 + 2)	1727	1610
Day 7 (13 + 4)	1797	1648
Day 8 (15 + 6)	1805	1623
Day 9 (17 + 8)	1787	1720
Total	15911	14765
Average	1768	1640
Max Daily	1806	1720
Min Daily	1727	1578

Assumes 2 spacecraft in interleaved orbits. Data acquired by counting scenes centers on U.S.G.S. - Edition 1 - Landsat Coverage maps.

In Method Two, the sensors would be cycled off to conserve power during periods when the spacecraft is over open water for longer than 10 scenes. This method also includes coverage of Antarctica. Total global coverage amounts to 14,765 scenes per repeat cycle and the average acquisition is 1640 scenes/day.

For the purpose of establishing overall ground system loading, Method One was selected as the spacecraft operational mode. This is in concurrence with the mode being considered at GSFC. Selection of either method will have little effect on the ground system because similar data reduction can be achieved at the DIS by turning off the tape recorders while the spacecraft is over open ocean.

As has been indicated above, the scene acquisition requirements for all the missions is a subset of all the land mass of the world from 60°S to 70°N. The total number of scenes required to cover the global land mass from 60°S to 70°N is 9103 per repeat cycle, resulting in an average of 1011 scenes per day for a 2 satellite system. The figure of 1011 scenes/day represents a starting point for the number of scenes per day which must be acquired to satisfy all the mission requirements. It will be shown in subsequent sections how this number will be reduced to 438 scenes per day.

2.3.2.2 Agricultural Mission Requirements

In order to estimate the number of scenes required to satisfy the agricultural mission, an analysis of global crop areas was performed. Using the U.S.G.S. Landsat coverage maps and a tabulation of major crop producing areas obtained from the Oxford Economic Atlas of the World, the number of scenes necessary to assess global crop production of wheat, corn, soybeans, rice, potatoes, and sugar was computed. The total number of scenes required to cover these major crop producing areas during their respective growing seasons for each month was computed, using crop calendar information from the World Agricultural Atlas. The monthly total scenes obtained represent the number of Landsat images necessary to cover the area planted with the crops of interest during that month. The largest number of scenes are required in May - 4050, the smallest in Juanuary - 1400, and the average - 2848 (see Table 2-3). Assuming 2 spacecraft, these crop areas can be completely covered every nine days.

Table 2-3. Monthly Agricultural Acquisition Profiles

	Monthly Totals	Daily Average	≤ 90% Cloud Cover Monthly Totals	≤ 90% Cloud Cover Daily Average
January	1400	156	970	108
February	1800	200	1318	147
March	2075	231	1500	167
April	3075	342	2156	240
May	4050	450	2827	315
June	3925	437	2858	318
July	3675	409	2634	293
August	3475	387	2564	285
September	3875	431	2770	308
October	3300	367	2374	264
November	2000	223	1403	156
December	1525	170	1076	120
Average	2848	317	2038	227

The resulting average daily acquisition requirements for complete coverage are most severe in May - 450 scenes/day, least severe in January - 156 scenes/day, with the average month requiring 317 scenes/day. (See Table 2-3).

If cloud cover were not a factor, these numbers would represent the total number of scenes required by the agricultural mission. However cloud cover plays a major role in determining the data which may be obtained on a given day. In order to take the cloud cover distributions of crop production areas into account, the 29 cloud cover regions (Figure 2-3) outlined in "World Wide Cloud Cover Distribution for Use in Computer Simulations" were transposed to

Landsat coverage map overlays (Figure 2-4). Probabilities for 100% cloud cover in each cloud cover region were used to compute the expected number of agricultural scenes during each month with 90% cloud cover or less. (Cloud cover probabilities given in 10% increments). Since scenes with 100% cloud cover are of no value to the agricultural mission, the resulting number of scenes presented in Table 2-3, with 90% cloud cover or less are assumed for the agricultural loading profile. The largest occurrence is in June - 318 scenes/day, the smallest is in January - 108 scenes/day, and the average/month is 226 scenes/day. The average number of 318 scenes/day in the highest activity month (June), will be used as the agricultural requirement. Cases in which greater than 318 scenes/day are required are discussed in Section 2.3.3 (The Priority Hierarchy).

2.3.2.3 U.S. Coverage Requirements

It is assumed that it is required to acquire imagery over the U.S. whenever it is available. In order to size this problem, Landsat coverage maps were examined to determine the maximum number of U.S. scenes obtainable in one day. The maximum number of scenes covering the U.S. landmass obtainable by a 2 satellite system in one day is 73. This number is used in the sizing of this portion (U.S. coverage) of the pipeline.

The cloud cover statistics for the U.S. are applied, similarly to the procedure used in analyzing the agriculture mission to remove the average number of scenes with >90% cloud cover. However, in order not to have a situation where extreme circumstances (exceptionally clear days) were driving up the acquisition requirements of both the agricultural and the U.S. scenes, the number of scenes edited for >90% cloud cover was reduced to a 3-sigma number. A detailed explanation of the assumptions made and the probabilities involved is presented in Section 2.3.2.4. Basically a normal distribution is assumed with mean = 14 and standard deviation = 3.35, resulting in a 3-sigma number of four scenes removed (lower 3-sigma bound). This results in a total of 73 - 4 = 69 U.S. scenes/day to be considered.

The next step was to remove the number of scenes from the 69 that were included in the agricultural mission requirements. This resulted in

$$\text{(69 scenes)} \quad \left(1 - \frac{\text{318 Ag. scenes taken}}{\text{1011 total landmass scenes}}\right) = 47.3 = 48 \text{ U.S. coverage}$$

scenes.

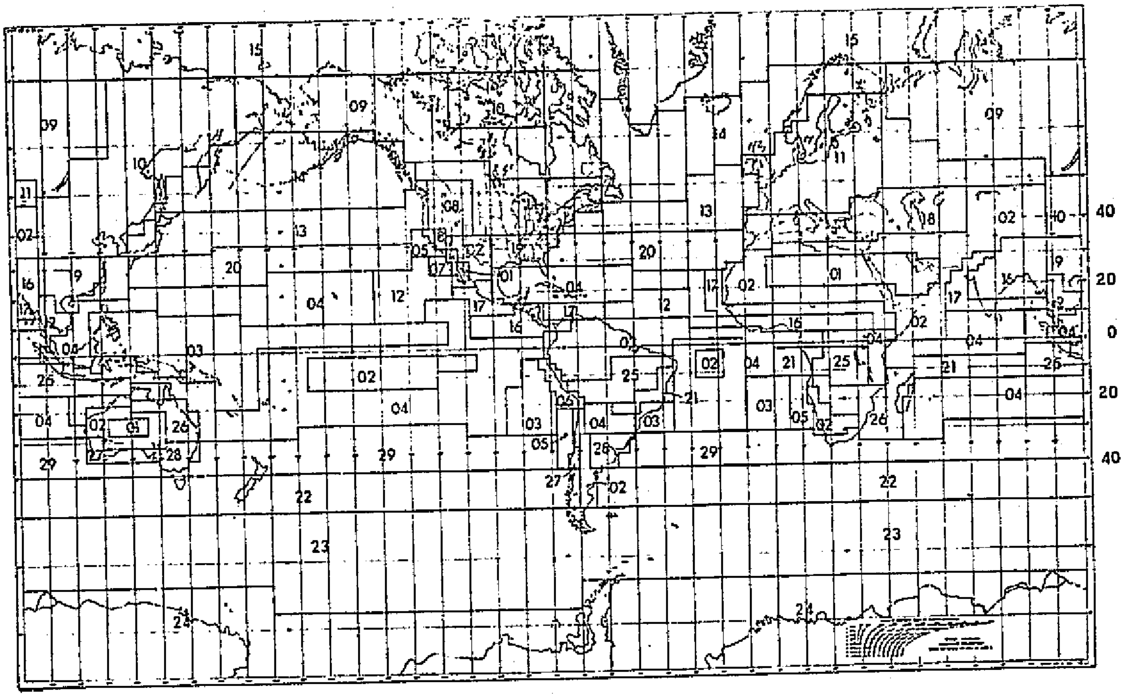


Figure 2-3. Global Cloud Cover Regions

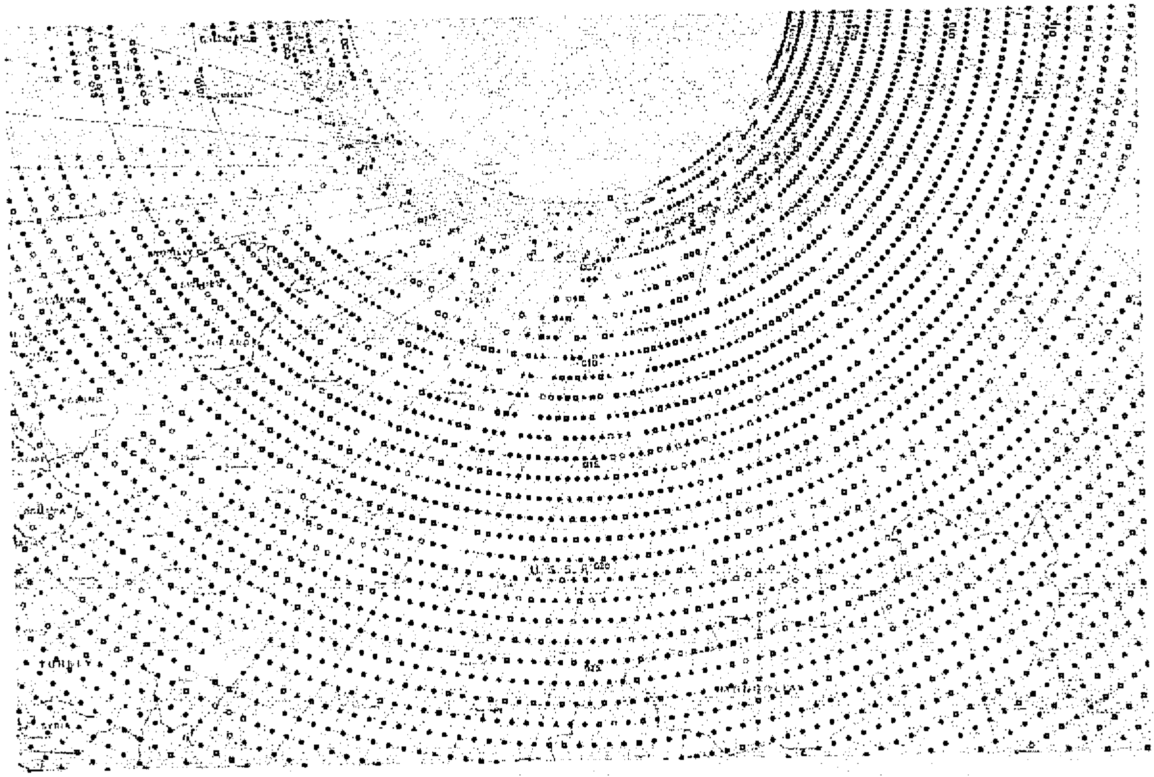


Figure 2-4. Landsat Coverage Map Overlays

Complete coverage of the U.S. will then require the selection of 48 additional scenes daily.

2.3.2.4 Rest of the World Requirements

The mission requirement for rest-of-the-world (ROW) coverage is to obtain scenes of the land mass of the world from 60^{o}S to 70^{o}N on a quarterly basis, excluding the U.S. scenes and those acquired for the agricultural mission. The following calculation is used to derive the number of candidate scenes for rest-of-the-world coverage:

+ 1011	-	Avg. scenes/day for 60^{o}S to 70^{o}N land mass
- 450	-	Average agricultural mission scenes/day considered (based on peak activity month)
- 48	-	Number of U.S. scenes/day expected (based on maximum available scenes)
513	-	Candidate rest-of-the-world scenes/day

The 450 agricultural mission scenes/day were eliminated from consideration because any of these scenes having 90% or less cloud cover will be taken as part of the agricultural mission. If a scene has >90% cloud cover it is not considered useful for the rest-of-the-world mission. The 48 U.S. scenes/day were also removed from consideration. It may be argued that when the agricultural mission demand is less than 450 scenes/day, the requirement for U.S. coverage will increase beyond 48 scenes/day. While this is true, the major effect on a fixed size "pipeline", of less than the peak month agricultural mission demand is an increase in the candidate rest-of-the-world scenes being accepted. The interrelationships of the three mission drivers and their interaction in the sampling strategy is discussed further in Section 2.3.3.

Several strategies for selecting the number of scenes from the 513 daily candidates for the rest-of-the-world coverage were considered. The simplest but least efficient approach would be to acquire all 513 scenes every day. A slight refinement of this would be to use only scenes with cloud cover less than or equal to 90%, resulting in a still unwieldy total of approximately 363 scenes/day. A third method, probably the least reliable for distributed coverage is to select some number of scenes N (N<363), and to acquire the first N scenes which are not 100% cloud covered each day.

The final method, a probabilistic approach, involves determining the required number of scenes (N scenes/day) based on probability, and then selecting the most valuable N scenes each day, based on each scene's cloud cover probability. This method called the probabilistic sampling strategy, was selected for implementation.

The underlying concept for this probabilistic sampling strategy is to assess the cloud cover for a day's scenes and to select those scenes which are most valuable, hardest to get, or not previously obtained in that quarter. In order to ascribe a value to the occurrence of a certain cloud cover X over a particular scene, we have to know the statistics of the cloud cover that generally occur in the scene area. Each scene is located in one of 29 cloud cover zones (See Section 2.3.2.1) and has a cumulative probability curve such as in Figure 2-5A. Typical interpretation of this curve is as follows: The probability is .1 that the cloud cover of a particular scene will be 30% or less. As shown in Figure 2-5B, the farther the curve moves to the right, the harder it is to obtain the scene with low cloud cover. For example, for the scene with the curve labeled "easy", there is a high probability of obtaining low cloud cover scenes while for the hard curve, there is a low probability of obtaining a low cloud cover image.

In the Landsat D two-satellite system there will be 10 passes/swath/quarter, one every 9 days. This means that there will be 10 chances to acquire each scene in a quarter. Statistically then, each scene can be expected to occur with its P = .1 probability cloud cover or less, once per quarter. Given a scene's cumulative probability curve and its actual cloud cover on any given day, the most valuable N scenes for that day are selected as the N lowest values of $X_{ACT} - X_{(P_{cc}=.1)}$, where X_{ACT} is the scene's measured cloud cover on that day and $X_{(P_{cc}=.1)}$ is the upper limit of the cloud cover expected for that scene with a .10 probability. In effect, the occurrence of a cloud cover value for a scene is being normalized to the expected best value within 10% probability of occurrence for that area. This evaluation allows the selection of the N most valuable scenes.

Now that the method of selecting the most valuable scenes has been determined, the following develops the method for determining N, the number of scenes to be selected from the 513 candidate rest-of-the-world scenes each day. The value of N will be computed for the first

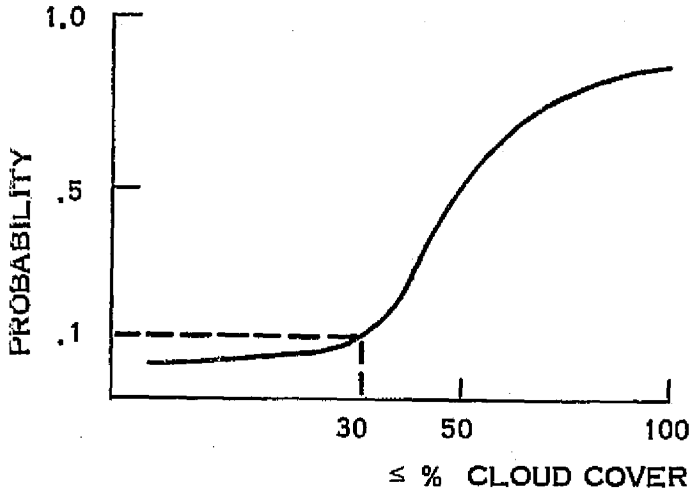


Figure 2-5A. Cumulative Cloud-Cover Probability Curve

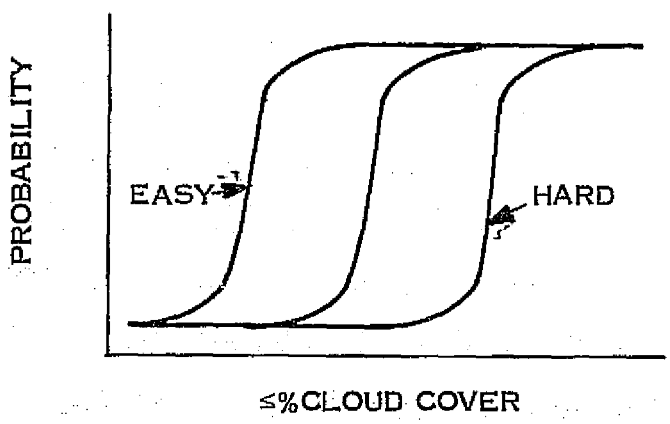


Figure 2-5B. Variation in Cumulative Cloud-Cover Probability Curves

pass in each quarter and then tested against achieving the mission requirements for the entire quarter. Let us first note that the occurrence of a particular cloud cover will uniformly fall in any of the tenths from 0 to 1.0 on its cumulative probability curve. That is, a $P_{cc} = 0$ to $P_{cc} = .1$ cloud cover is as equally likely as a $P_{cc} = .6$ to $P_{cc} = .7$ cloud cover or with any other one-tenth increment of cumulative probability. We define an occurrence of cloud cover associated with the probability $P_{cc} = 0$ to $P_{cc} = .1$ as a success, and an occurrence from $P_{cc} = .1$ to $P_{cc} = 1.0$ as a failure. The occurrence of a cloud cover on each of the 513 candidate rest-of-the-world scenes may be regarded as independent Bernoulli trials with a probability of success $p = .1$ and a probability of failure $q = .9$. The fact that successive scenes on a given pass do not have independent cloud cover probabilities will be overlooked during this analysis. We can now begin to set a value for N, the number of scenes selected from the 513, by determining how many scenes will achieve at least their $P_{cc} = .1$ cloud cover probabilities, or simply stated "how many successes will occur in the 513 Bernoulli trials"?

The probability that a certain number of successes, k, will occur in N Bernoulli trials can be computed using the binomial distribution as follows:

$$b\ (k;n,p) = \binom{n}{k} p^k\ q^{n-k}$$

Next, if we note that $pn \geq 5$ and $pnq \gg 1$, the Demoivre-Laplace limit theorem allows us to approximate the binomial distribution by the normal or Gaussian distribution of the form:

$$P(k \leq x) \equiv \phi \left(\frac{x-np}{\sqrt{pnq}}\right) \equiv \int_{-\infty}^{x} \frac{1}{\sqrt{2\pi pnq}}\ e^{-\left[1/2 \left(\frac{x-pn}{\sqrt{pnq}}\right)^2\right]} dx$$

where np = the mean or expectation

npq = the variance

$\sqrt{npq}$ = the standard deviation

For the case of interest

$p = .1$, $q = .9$ and $N = 513$

$pn = 51.3$

$\sqrt{pnq} = 6.79$

and $pn + 3\sqrt{pnq} = 71.67 \approx 72$ scenes

This means that if we size our system to accept 72 rest-of-the-world scenes, 99.87% of the time there will be sufficient capacity to accept all scenes with cloud cover less than or equal to their respective $P_{cc} = .1$ values. Therefore, for the first pass in a quarter, by sizing our capacity to accept 72 rest-of-the-world scenes per day, we will acquire the most valuable scenes ($P_{cc} \leq .1$) 99.87% of the time.

We will now look at what happens on succeeding passes in a quarter. Not all 513 candidate scenes achieve the cloud cover value associated with $P_{cc} = .1$ during a quarter. In fact, on the average B scenes will not achieve the value associated with $P_{cc} = .1$ in 10 passes:

$$B = (1-i)^{10} (513)$$

This relationship, shown in Figure 2-6, indicates that, on the average, 179 scenes will not achieve the $P_{cc} \leq .1$ value in 10 passes, 55 scenes will not achieve the $P_{cc} \leq .2$ value in 10 passes, and so on.

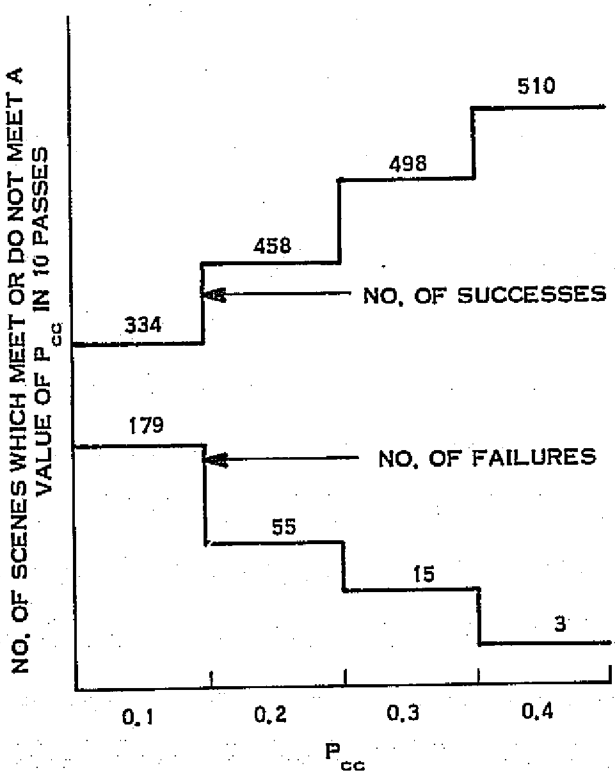


Figure 2-6. Average Scene Cloud Covers in 10 Passes

Using this sampling strategy we will not be able to acquire all 513 scenes required during a quarter by limiting "acceptance" to those scenes with cloud cover values ≤ to their $P_{cc} = .1$ values. Thus, we must raise our threshold of acceptance for a scene to cloud cover greater than that associated with $P_{cc} = .1$ on succeeding passes. This requires that a successively greater number of scenes are acquired on each succeeding pass. To avoid this situation, the sampling strategy is modified as follows:

If a scene has been accepted with a cloud cover value $P_{cc} = a$, and on a succeeding pass the same scene occurs with cloud cover $P_{cc} = b$, the scene will only be retaken if $a - b > .1$. This differential of .1, called the cloud cover improvement criterion, has been arbitrarily selected and its importance will be discussed at a later time. This modification provides that a scene will not be retaken during a quarter unless it is better by a certain amount (at least .1 probability).

The modified sampling strategy allows us to maintain the sample (N) at a maximum of 72 scenes/day while accepting "untaken" scenes at higher and higher values of P_{cc} (greater cloud cover). The analysis carried to this point cannot clearly determine whether all 513 candidate scenes will be taken in 10 passes. The value of the cloud cover improvement criterion is very important to the sampling strategy's success in meeting this goal.

Further analytic investigation becomes difficult for two reasons: (1) We have a modified hypergeometric distribution, and (2) the acceptance criterion generally rises (limit of acceptable cloud cover increases) for succeeding passes. A hypergeometric distribution occurs when sampling is made without replacement and the probability of success remains constant. On succeeding passes however, we are not sampling without replacement because we are retaking scenes if they are "better" by a certain amount. In addition, our probability of success must rise to meet the requirement of acquiring all 513 scenes in 10 passes. Therefore, at this point, a Monte Carlo simulation was used to further analyze the sampling strategy. A description of the simulation and its results will be presented in Section 2.3.4, following a discussion of the interrelationships of the three system drivers in Section 2.3.3.

2.3.2.5 PGDF Loading Analysis

As conceived in the GE design, the Product Generation and Dissemination Facility is a completely demand oriented system. This implies that no film products are made, no geometric corrections applied, etc., until there is a specific request for that particular item. Initial estimates of system size and operation must thus be based on projected demand for PGDF products.

The Department of Interior's EROS Data Center was contacted to obtain information on present product order volume and product mix. This data is presented in Table 2-4. It should be noted that while the film volume is substantial in all four years, the tape volume started from essentially zero and has just begun to grow. For this reason, the film demand for the 1980 time frame is based on a linear estimation, while the projection of tape demand for the same period uses a nonlinear estimation. These projections are shown in Figure 2-7 and 2-8. The nonlinear projection for tape demand is further justified by the fact that investigators familiar with the Landsat program are of the opinion that as the program evolves toward a more operational system the demand for digital data will continue to grow. It is felt that these projections are reasonable, and they will be used to size the PGDF subsystems.

Table 2-4. Reported PGDF Demand

	1973	1974	1975	1976
Landsat Imagery: (Orders/Year)	81,071	157,178	195,125	263,000
Landsat Tapes: (Orders/Year)	10	228	879	2,200

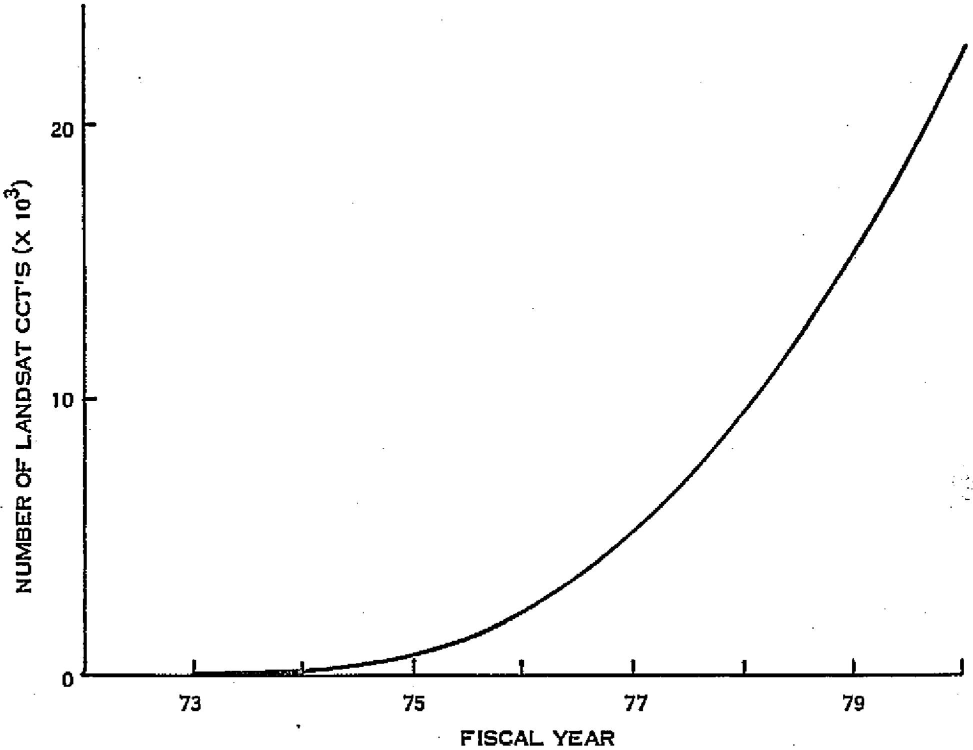


Figure 2-7. Demand Projection for Tape Products

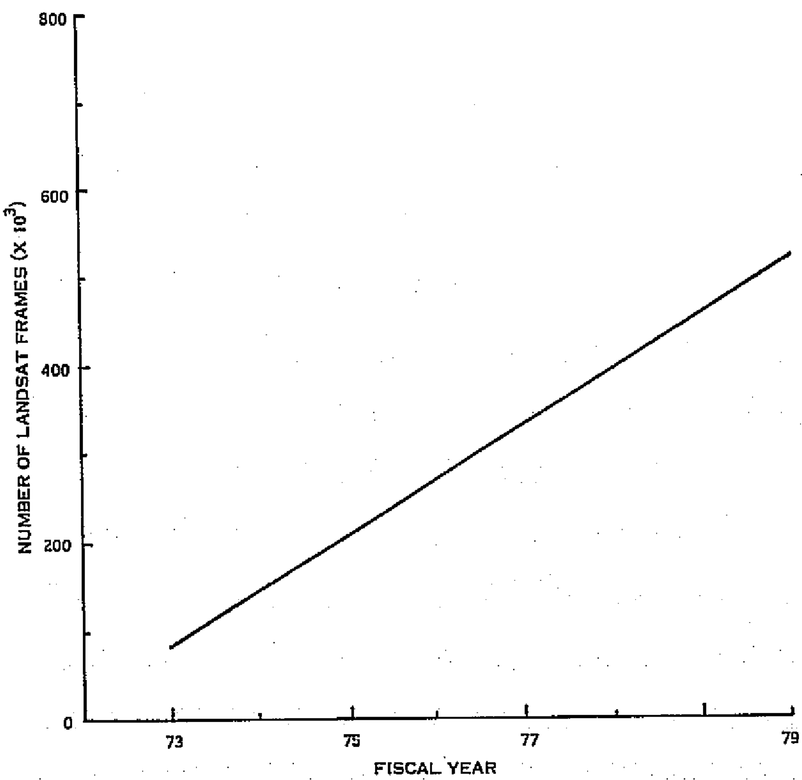


Figure 2-8. Demand Projection for Film Products

The projections of demand result in an estimate of 23,000 digital tapes and 515,000 frames of imagery per year, or 63 digital tapes and 1411 frames per day. Since almost all of the images ordered will require some geometric correction, dividing by six bands results in approximately 250 (rounded up from 236) scenes/day to be digitally processed. This assumes that the digital tapes requested will be largely a subset of the images ordered.

2.3.3 THE PRIORITY HIERARCHY

The previous sections have shown that the "pipeline" can be sized to handle 438 scenes/day, and meet the requirements of the various missions. The individual mission requirements are as follows:

Agricultural Mission	318 scenes/day
U.S. Coverage	48 scenes/day
Rest-of-the-World	72 scenes/day

This section examines the order of selection of these 438 scenes and the interrelationships between these and additional "special" mission requirements.

The overall sampling strategy is nominally designed to be implemented in the following fixed order:

(1) Accept 1011 scenes/day.

(2) Select 318 agricultural scenes (peak month average).

(3) Select the remaining 48 U.S. scenes.

(4) Fill up the remainder of the pipeline with the 72 most valuable rest-of-the-world scenes.

This nominal procedure will be altered by the following factors:

(1) The agricultural mission requiring more (rare) or less (most often) scenes than 318/day.

(2) The U.S. coverage mission requiring more or less than 48.

(3) Inclusion of additional scene requirements such as nighttime coverage, Antarctica coverage, catastrophe coverage, etc.

(4) Filling up the pipeline with the remainder of the 438 scenes/day.

The agricultural mission is the main driver on scene acquisition requirements and its large seasonal swings in scene requirements cause major changes in the ability of the system to meet all the mission requirements. During the months of May, June and September when the agricultural scene demand is quite high, there will be little "room" for accepting many extra scenes. As will be shown in the simulation results (Section 2.3.4), the positioning of a quarter (ROW requirement) with respect to these peak months is of prime importance. Another key aspect of the operation of the sampling strategy during peak agricultural demand months is feedback from the agricultural mission, concerning any reduction of their demand load. If one scene per biophase is sufficient, a reduction in scenes required may be permitted after acquisition of usable scenes during a given biophase. For example, if a remarkably clear day occurs at the beginning of June, the system will overload with agricultural scenes and will be unable to take all the rest-of-the-world scenes it might have acquired under "average conditions". In this situation, a revision of the scene requirement allows for more rest-of-the-world scenes on the next pass, thus somewhat making up for the previous omissions.

The agricultural mission requirement is usually much less than the peak 318 scenes/day used in sizing. Its yearly average requirement is 227 scenes/day and in the lightest month it only requires 108 scenes/day. Under these conditions there is ample "room" in the pipeline to accept "special" requirement and "rest-of-the-world" scenes.

Each requirement for scene acquisitions is assigned a priority for its execution. Each day (or each 12 hour period, as discussed later), the hierarchy of priorities is evaluated and the 438 highest priority requirements are filled. Normally, catastrophe-type requirements are assigned a very high priority while research oriented requests are assigned a low priority.

2.3.4 EDITING SIMULATION

As mentioned in Section 2.3.2.4, analytic modeling of the overall sampling strategy is difficult because of the unique scene requirements of the various missions. For this reason an empirical simulation was performed. In this simulation the scene requirements

of the agricultural mission and the cloud cover of each of the rest-of-the-world scenes are determined by random number generators. The simulation and its results are described below.

The simulation involved selecting an agricultural mission requirement, determining how much room was left in the pipeline for rest-of-the-world scenes, and filling it up with them. This was simulated for 10 passes (one quarter) at which point the sampling strategy was evaluated based on the occurrence of two kinds of errors. Fatal errors were defined as not acquiring all 513 rest-of-the-world scenes at least once per quarter. Non-fatal errors were defined as not acquiring the best cloud-cover that a scene exhibited during the quarter.

The simulation was made for the peak demand 5-month period of the year, that period when the agricultural mission requirement is highest. For the months April through August, a normal distribution was assumed for the agricultural scene requirements with means = 239,314,318,293,285, respectively and standard deviation = 9.66. The 10 passes were apportioned to the individual months, 3, 3, and 4, and the agricultural requirements randomly generated from that months $R(\mu,\sigma)$. One half of the simulation runs were made with a quarter (10 passes) starting in April (order A), one half with a quarter starting in June (Order B).

Once the agricultural scene requirement for a pass is determined, the number of allowable rest-of-the-world scenes is directly computed. $\left(N = 438 - R(AG) - 48\ (US)\right)$. The actual cumulative distribution functions for the 29 cloud cover zones were not utilized in this simulation. Referring to Figure 2-3, it can be seen that a cloud cover value for a scene can be represented by its cumulative probability density and further, that these cumulative probability densities are uniformly distributed. For each pass, 513 random numbers are generated from the uniform distribution (0,1) and are then ordered in ascending order along with their associated identification numbers. On the first pass, the N scenes with the lowest probability of cloud cover occurrence are selected. On succeeding passes, the list is again ordered and the most valuable (lowest probability) scenes again taken. However a scene is not retaken unless it is at least .1 better (lower) than the scene that was already taken.

For the twenty acquisition quarters simulated, no fatal errors were observed. On the average, nonfatal errors occurred on 8.8% of the rest-of-the-world candidate scenes. This was split - 6.3% in order A, 11.3% in order B. On the average, for each 10 passes there was room for 87 scenes beyond those called for by the sampling strategy (Antarctica, catastrophes, etc.). It is expected that in other parts of the year (lower demand) this number would be much larger. The number of times a scene was taken during 10 passes is rather important. On the average 60.1% were taken once, 19.7% - twice, 12.2% - three times, 6.0% - four times, 1.5% - five times, and .5% - greater than five times.

2.3.5 CONCLUSIONS

It has been shown that a probabilistic sampling strategy will satisfy the mission requirements as stated and will also result in a significant reduction in the number of scenes per day to be processed. It is important however, to understand the limitations of the output of the sampling strategy.

Using this sampling strategy, all rest-of-the-world scenes will be obtained at least once per quarter. In addition, 88-94% of the scenes will be obtained at approximately the lowest ($< \Delta P = .1$) cloud cover that was available in that quarter. The remaining 6-12% of the scenes were not taken at the lowest cloud cover because more valuable scenes were being taken at that time.

While quite effective, this sampling strategy has some inherent shortcomings. It will not provide the whole world cloud free in a quarter. It will also not acquire the entire cloud free land mass area that occurs during a quarter. These requirements are not the areas addressed in this study. Meeting the additional requirements would require more analysis and surely result in many more scenes being taken than with the current sampling strategy.

SECTION 3

DATA TRANSMISSION METHODS

Once the thematic mapper and/or multispectral scanner data has been relayed to White Sands, via TDRSS, the problem of data transfer to the various ground processing centers and on to the users must be solved. Satellite data transfer to both domestic and foreign locations is examined in Section 3.1. Terrestrial and common carrier data transfer alternatives are briefly examined in Sections 3.2 and 3.3 respectively.

3.1 SATELLITE DATA TRANSFER

3.1.1 DOMESTIC SATELLITE DATA TRANSFER

Typically, Domsat transponders have bandwidths of 34 or 36 MHz. Thus, with QPSK data, one transponder will be needed for a 50 Mbps data link and one half of a transponder will be required for a 25 Mbps data link.

Three Domsat service supplier organizations were considered for availability and costs: Western Union Telegraph Company (WESTAR), RCA Global Communication, Inc. (SATCOM) and the American Satellite Corporation (WESTAR).

The WESTAR Communications Satellite System became operational on July 15, 1974, using the first of two 12-transponder satellites. It provides data, as well as voice and video leased private line services in the 4/6 GHz band. The satellite, as well as the earth stations, are owned by the Western Union Telegraph Company. The system has earth stations at New York, Chicago, Los Angeles, Dallas and Atlanta (1975).

The RCA Satellite Communications System is operated by RCA Global Communications and RCA Alaska Communications. Two 24 transponder SATCOM Communication Satellites have been launched and are now becoming operational (1976).

RCA has earth stations in New York City, San Francisco and Los Angeles within the Continental United States, along with others outside CONUS (1975). Private line analog and digital voice,

data, and video services are available. Previous to the launch of the SATCOM satellites, RCA leased transponders on TELESAT and WESTAR I.

The American Satellite Corporation, owned by Fairchild Industries, Inc. operates a domestic satellite system based on earth stations and Satellite Access Centers (SAC's) that it owns and operates in conjunction with fully protected transponders leased on the WESTAR I Satellite (4/6 GHz band). The American Satellite Corporation operates earth stations near New York, Los Angeles, Dallas and San Francisco. The New York and Los Angeles earth stations are inter-connected via ASC owned microwave repeaters to SAC's (or central offices) in these cities. SAC's are also in operation in Chicago using leased terrestrial microwave facilities to connect to the nearest ASC earth station (New York).

Customer site earth stations include five for the U.S. government, built under Defense Communications Agency (DCA) contracts. These stations are located at Loring AFB, Maine; Offutt AFB, Nebraska; Fairchild AFB, Washington; Moffett Field, California; and Centerville Beach Naval Facility in California. ASC's present plans (1975) are to build 8 more earth stations by 1980 to serve some 20 cities. Among these will be new earth stations to serve Washington, D.C.; Atlanta, Georgia; Pittsburgh, Pennsylvania; and Seattle, Washington. The American Satellite Corporation also plans to have its own K-Band satellites in the early 1980's.

These three satellite communications systems will be in operation in the 1980's and, therefore, will be potentially available for Landsat use.

Estimated costs of Comsat transponders and earth stations were obtained by telephone conversations with Western Union, RCA Globcom and American Satellite Corporation. In addition, the costs of purchasing an earth station were obtained from Western Union, American Satellite and Scientific Atlanta, Inc. The costing data from these sources are given in Table 3-1.

3.1.2 INTERNATIONAL SATELLITE DATA TRANSFER

There are two possible scenarios for data transfer to foreign users: (1) the raw data is immediately transferred to foreign users; or (2) the data is transmitted to the CDPF for some processing and then relayed to foreign users.

Table 3-1. Estimated Costs of Domsat Transponders and Earth Stations

Component	Western Union[2] (WESTAR)	RCA Globcom[3] (SATCOM)	American Satellite[4] (WESTAR)	Scientific [5] Atlanta, Inc.	Remarks
Transponder*	$1.7M/Yr	$1.4M/Yr	$1.7M/Yr	--	Protected*
One-Half Transponder*	$0.85M/Yr	$0.7M/Yr	$0.85M/Yr	--	Protected*
Earth Station					
Lease**	--	$204K/Yr	$168-204K/Yr	--	Fully Redundant Earth Station
Buy***	--	--	$400K	$350K**** (TX/Rec $550K)	Fully Redundant. 10 meter dish, Uncooled para amp HPA (several hundred watts)

* Protected: a replacement transponder is designated and service will not be pre-empted.

** 10 year contract. These estimated costs include maintenance. Fully redundant earth stations.

*** These estimated costs do not include maintenance or property; however, they do include installation. These costs are for either a "transmit only" or "receive only" earth station. Earth station fully redundant.

**** This estimated cost derived from data from Scientific Atlanta on 1.5 Mbps earth station and data from Magnavox on 50 Mbps Modems.

Technologically, the most efficient method of relaying data to foreign users is via a communications satellite. The INTELSAT satellite system is presently the sole carrier of commercial international communications traffic. A list of the most likely foreign users, the location of the INTELSAT ground station, the gateway city for the Intelsat link, and the location of the LANDSAT ground station is as follows:

Country	INTELSAT Terminal	INTELSAT Gateway	Landsat G/S
Canada	Mill Village		Ottawa
Brazil	Tangua	Rio de Janero	Cuiaba
Italy	Fucino	Rome	
Zaire	Nsele	Kinshasa	Kinshasa
Iran	Asadabad	Tehran	Tehran
Chile	Longovilo	Santiago	
Japan	Obaraki	Tokyo	Tokyo

INTELSAT Corporation, the owner and director of the INTELSAT system, is a non-profit organization composed of member countries that use the system. In each member country, a signatory is designated as the sole organization with the right to access an INTELSAT satellite. In the United States, the signatory is Comsat Corporation. In Great Britain, the signatory is the British Post Office. In most other foreign countries, the signatory is some government agency.

Since Comsat Corporation is the only U.S. organization that has access to an INTELSAT satellite, constituting a monopoly, the Federal Communications Commission has issued the following regulations concerning Comsat's operations: (1) Comsat must sublease the rights to access the satellite to other companies; (2) Comsat may not lease service directly to the public. To date, Comsat has made arrangements with four U.S. companies (RCA, Western Union, ITT, and ATT) to provide commercial traffic to the public.

Three methods of using the INTELSAT system -- voice-grade rental, wideband rental, and transponder rental -- were investigated, and are discussed in order below.

The reliability figures for the INTELSAT System for the year 1975 (average) are as follows:

Space Segment	99.992
Earth Segment	99.952
Overall	99.892

It has been suggested that starting in about 1980, the INTELSAT V system, with Time Division Multiple Access coding, (with hopefully more data capability at lower cost) will be available.

INTELSAT has indicated that voice-grade channels with capacities of 64K bit/sec. will be available in quantity over any ocean by the 1980 time frame (see Figure 3-1). INTELSAT's rate for a one-year lease of a voice-grade channel to a signatory is about \$8000. It is important to point out that the charge for a voice-grade link to a customer must also include the carrier's costs for the ground stations, which are much higher, since the ground stations are operated on a profit basis.

Two carriers were contacted for representative rates for half-link costs. These carriers operate the transmission link from a gateway city, to a ground station, and on to a satellite. Each foreign country has its own charge for the half link from the satellite to its gateway. A relay through a European country is necessary for countries served only by the Indian Ocean Satellite.

The gateway cities for White Sands and Goddard are San Francisco and Washington, respectively. Data has to be transmitted to the gateway cities via a terrestrial data link (see Section 3.2) or via a domestic communications satellite. Costs from San Francisco and Washington to their respective satellites are \$12,000 and \$6925/voice-grade channel/month. Estimated half link costs from the satellite to each of the foreign countries per voice-grade channel per month are as follows:

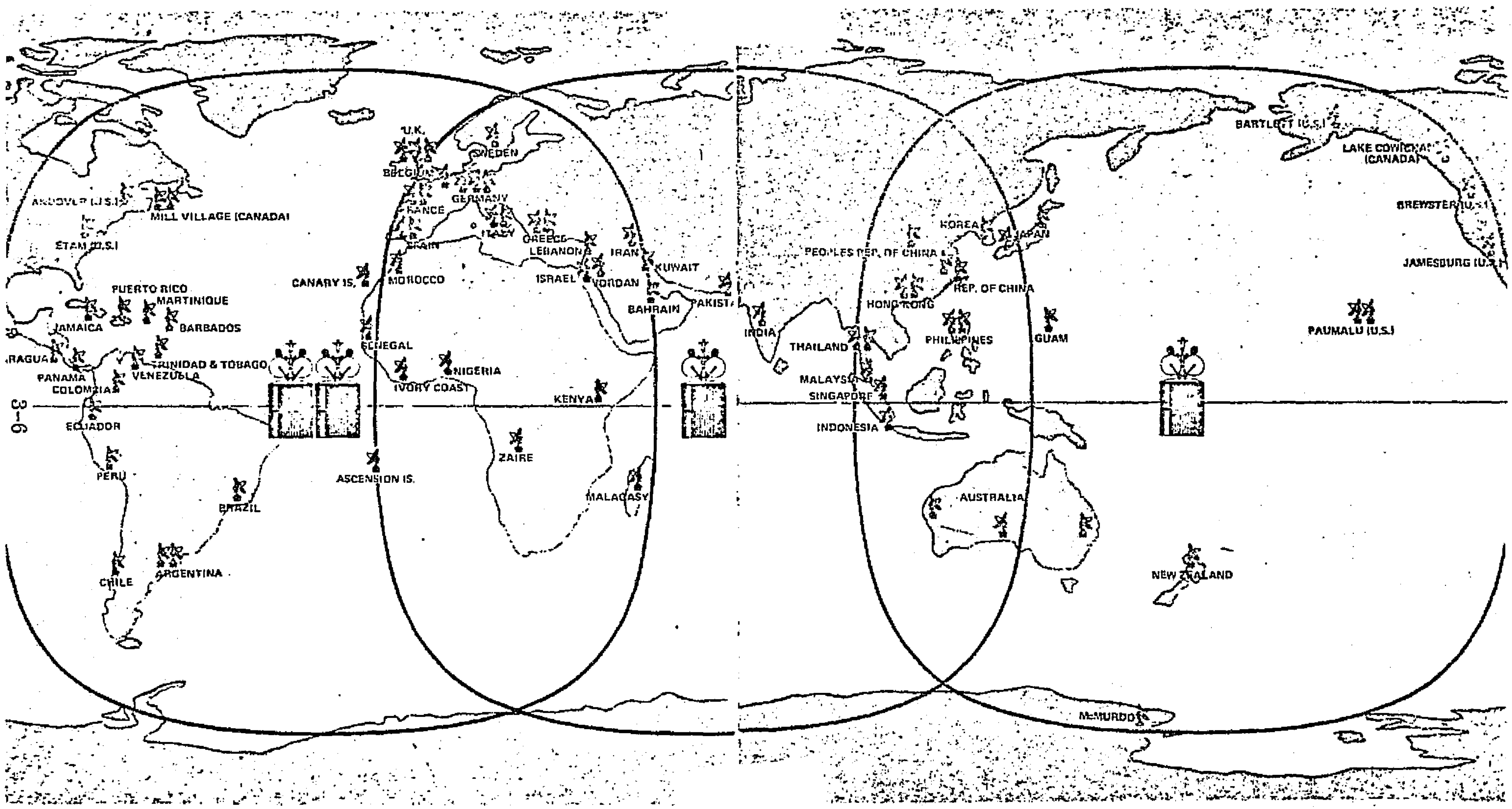


Figure 3-1. The Global System of INTELSAT IV Satellites and Operational Earth Stations (as of December 1972)

Brazil	\$22,800-30,400
Italy	21,900-29,200
Zaire	24,000-32,000
Iran	33,300-44,400
Chile	30,400-40,600
Japan	37,200-49,600

At 64K bits/sec., one voice-grade channel can handle about 5.5 gigabits/day with continuous transmission. The expected peak data volume per day is 2.13×10^{11} bits/day for a 2200 km coverage circle. Thus, peak data rates would require about 40 voice-grade channels.

The possibility of obtaining wideband service from the INTELSAT system was briefly investigated. It is possible to lease a number of voice-grade channels on the satellite; however, the cost is essentially n x c where n is the number of channels leased, and c is the single channel cost. Discounts, on the order of 10 - 20% are available to lessees of large groups of channels. Present tariff restrictions, international agreements, etc., prohibit channels of greater width than voice grade from being leased, and it was the collective opinion of all parties contacted that this restriction would remain indefinitely.

The final alternative investigated was renting an entire transponder on the satellite. Investigation revealed several legal complications for this option. One protected (with back-up) transponder, with 36 MHz bandwidth which can be used to relay 40 Mbps now, or 60 Mbps (using QPSK) in the future, may be leased by a signatory for \$3M/year. It is also possible to rent one-half or one-quarter of a transponder with proportional associated costs and bit rates. Several countries, such as Norway, Brazil, the Phillipines, Algeria, and Nigeria, have done this. However, these transponders may be used for domestic transmission only. If the transponders could be used for international traffic, users would in effect receive a preferential rate (below that of normal users). For example, if the U.S. and the U.K. rented a transponder for international use at \$3M, they could derive 1000 voice-grade channels or 2000 half links (referreu to as units of utilization). This amounts to \$125/half link/month. The standard INTELSAT rate for rental of a half link

(voice grade) to a signatory is $690/month. Therefore, international traffic on a leased transponder would result in a preferential rate. Present INTELSAT regulations do not allow preferential rates.

In one instance in the past, this restriction was relaxed. Spain and Mexico jointly rented one-half of a transponder on a two-year lease for continuous television broadcasts. This exception was approved by the directing body of INTELSAT as a one-time event. This leads to a complex policy question: "Would NASA also be granted an exception from these restrictions for purposes of data distribution associated with the Landsat D program?" This requires that INTELSAT be petitioned by the signatories of the countries involved for a ruling allowing an exception to current INTELSAT regulations. There would be many legal and political implications to such an exception and deliberations are likely to drag out for a lengthy period of time. The final decision would be based on a vote of all INTELSAT signatories. If the exception is granted, an additional problem will have to be solved. Comsat (the U.S. signatory for INTELSAT) will be the holder of a lease on a transponder (or some fraction) at $3M/year, specifically for NASA's application. Presently, the FCC and the Office of Telecommunication Policy forbid Comsat from leasing service directly to users (NASA) to preclude unfair competition with outlet carriers.

There have been two instances in which Comsat has been allowed to rent directly to a user for reasons of national interest. One of these was a DOD link to Southeast Asia several years ago, and the other was a NASA link necessary for the Apollo program. In both cases, the exceptions were terminated after a short period of time, and the customers were obliged to deal with one of the outlet carriers (RCA, Western Union, ATT, ITT). NASA would probably be required to deal with one of the outlet carriers for the required transponder rental. Since both Comsat and the outlet carrier are profit-making organizations, it has been estimated that at a minimum, the transponder rental fee would double, without even including additional fees for the required earth station, peripherals, etc.

Clearly, communications satellites are technologically the most efficient method of transmitting large quantities of data internationally, but current international agreements and

regulations may have priced this method out of consideration. One possible alternative is for NASA to launch its own transponder, either on a new spacecraft, or as part of an existing program. It is not clear at this time whether arrangements would still have to be made with INTELSAT under these conditions.

3.2 TERRESTRIAL DATA TRANSFER

Terrestrial data transmission will be employed for various portions of the transmission links in conjunction with satellites. Data transfer links from White Sands to a DOMSAT (XMTR) facility, from a DOMSAT (RCVR) facility to a processing or production facility, or to an INTELSAT gateway facility, will be required.

A wideband data channel operating at 1.5 Mbps is available from the telephone company for digital data transmission. Costs for this service are:

1.	Intercity Service	\$64/mi/mo 50/mi/mo 40/mi/mo	1st 200 miles Next 300 miles >500 miles
2.	Access Lines/Modems	\$700/location	
3.	Intracity Service	\$60/mi/mo.	

Some typical transmission links and their approximate costs are:

White Sands - Washington, D.C.	\$90,000/mo.
White Sands - San Francisco	\$55,000/mo

Microwave links are another alternative terrestrial data transmission system. A rough cost estimate for a 10 Mbps system would be \$100K/terminal at each end with repeaters (\$100K each) spaced approximately every 30 miles.

As can be readily seen, the shorter the transmission distance, the lower the cost, while the DOMSAT link costs are independent of the transmission distance.

3.3 COMMON CARRIER DATA TRANSFER

If real time data transmission is not required for a given segment of the link, common carrier data transfer offers a much more inexpensive alternative. Representative air freight costs (obtained from TWA) are as follows:

	Price/lb.	25-lb.-parcel
Philadelphia to Albuquerque	$ .33	$18.00
Philadelphia to Sioux Falls		$28.00
Washington to London	$1.77	$44.25
Washington to Tokyo	$2.40	$60.00
Washington to Sydney	$3.13	$78.25

Note:
1. There is no special handling on TWA Air Freight
2. Minimum charge per parcel
3. Costs assume airport pick-up and delivery

Assuming an approximate weight of 25 lbs. for the tapes for one scene, the typical shipping costs are $25/scene-domestic and $50/scene-foreign for tape transmission of the data. The time delay associated with this method of transmission is 1/2 - 2 days

Air Mail costs would be approximately $80/scene, while surface mail cost would be approximately $15/scene. These two methods would probably involve transport delays of 2 days or longer.

SECTION 4

ARCHIVE ORGANIZATION AND COST

The Landsat D system will be capable of acquiring over 1768 scenes per day (using 2 satellites). Each scene contains six Thematic Mapper (TM) bands and five Multispectral Scanner (MSS) bands, resulting in a total data content of 3×10^9 bits per scene (raw data). High density digital tape (109×10^9 bits/reel) was chosen as the storage medium. Preliminary examination indicates that the cost of the tape is by far the largest "driver" in the archive element. Five archive organizational modes were created, and the cost of the tape to implement each is analyzed in this study. The modes range from permanent archiving of all data gathered, to one year archiving of only selected data.

NOMENCLATURE

HDT_R	High Density Tape containing "raw" or totally unprocessed digital data.
HDT_RR/C	High Density Tape containing "raw" digital data that has been radiometrically corrected. This archives a 1/3 reduction in the volume of the data.
HDT_A	High Density Tape containing selected (for minimum cloud cover and specific coverage frequency) radiometrically corrected scenes for entry into archive.
TM	The Thematic Mapper
MSS	The Multispectral Scanner

4.1 ARCHIVE ANALYSIS

The two-satellite system can gather over 1768 scenes per day with a total data content of over 5.304×10^{12} bits. The task of storing data of this volume requires an extremely high (data) density medium. Since the data must be recorded on tape at the input point of the system, the recording media associated with the two families of tape recorders (20 Mbps and 120 Mbps) potentially available to the system, are the prime candidates for archival storage media. Table 4-1 shows the various parameters associated with these high density digital tapes. The obvious cost and space savings associated with the 120 Mbps tape (1/6 the number of tapes and

Table 4-1. Alternative Tape Recorder Specifications

SPECIFICATION	20 MBPS RECORDER	120 MBPS RECORDER
Number of Tracks	14	42
Packing Density (kbits/in.)	17.5	26.0
Input Data Rates	500 Kbps-20 Mbps	500 Kbps-120/150Mbps
Input Format	Serial NRZL & Clock	Serial NRZL & Clock
Input Levels	DTL/TTL	TTL or ECL compatible
Output Data Rates	$\frac{20\ \text{Mbps}}{2^n}$ n=0, 5	Same as input
Output Format	Serial Data & Clock	Serial Data & Clock
Output Levels	DTL/TTL	"1" = 1±.25V, "0" = -1±.25V
Operation	Full Remote	Full Remote
Start Time	5 sec.	8 sec.
Stop Time	5 sec.	5 sec.
Fast Forward/Reverse	180 - 240 IPS	240 IPS +
Vendor	Martin Marietta	3 bidders: M. Marietta/Honeywell Ampex CEC (Bell & Howell)
Cost	\$67 - \$70K	\$225 - \$300K
Est. head life (operating hrs)	3000	1000
Est. tape life	no spec	75 Reads

recorders) led to its selection as the archival medium. This tape is presently in the evaluation stage by NASA while the associated tape recorders are in the first stages of procurement. Both tape and tape recorders will be available by 1978-1979.

There are a number of potential problems associated with the 120 Mbps magnetic tape including the requirement for using glass reels, high tape costs and small number of read cycles before data degradation.

Of the items considered, the one having the largest impact on the archive organization is the fact that the tape is reliably useable for about 75 read cycles.

Each reel may contain from 33 to 57 TM scenes and up to 547 MSS scenes. The read head is in contact with all tracks during the "search" mode. It is apparent that tapes containing frequently used scenes will wear out rather rapidly. To alleviate this problem, the High Usage Library (HUL) was conceived. This function consists of transferring high usage scenes (over 20 requests per year) onto working tapes which are replaced as wearout occurs. This effectively conserves the archival tapes while providing proper response to user requests. It is expected that about 10% of all HDT_A scenes received by the archive will fall into the high usage category. The HUL will be maintained for one year. Data from the EROS Data Center indicates that the highest demand for data occurs within 90 days of its acquisition. A continuing demand over several years is deemed to result from a lack of updated data. It is expected that even a higher percentage of the requests for an image will occur within the first 90 days when the availability of global updated imagery is improved.

4.2 ARCHIVAL ORGANIZATION OPTIONS EVALUATED

The following 5 modes of archival organization were evaluated and costs computed. The costs include the replacement of "spent" tapes but not the labor content in rerecording the data.

Mode 1 This provides the maximum feasible data. All "raw" data (HDT_R) is stored permanently, and all HDT_A data is stored for five years. A "High Usage Library" (HUL) is used to preserve the integrity of the HDT_A archival tapes. This mode provides access to all data gathered by the Landsat system for the total system life.

Mode 2 The raw data file is reduced by about 32% by limiting it to only land masses in the zone from $60^{o}S$ to $70^{o}N$. All HDT_A data is archived for one year and used in conjunction with a HUL. The "most useful" data acquired by the Landsat system is available for the total system life.

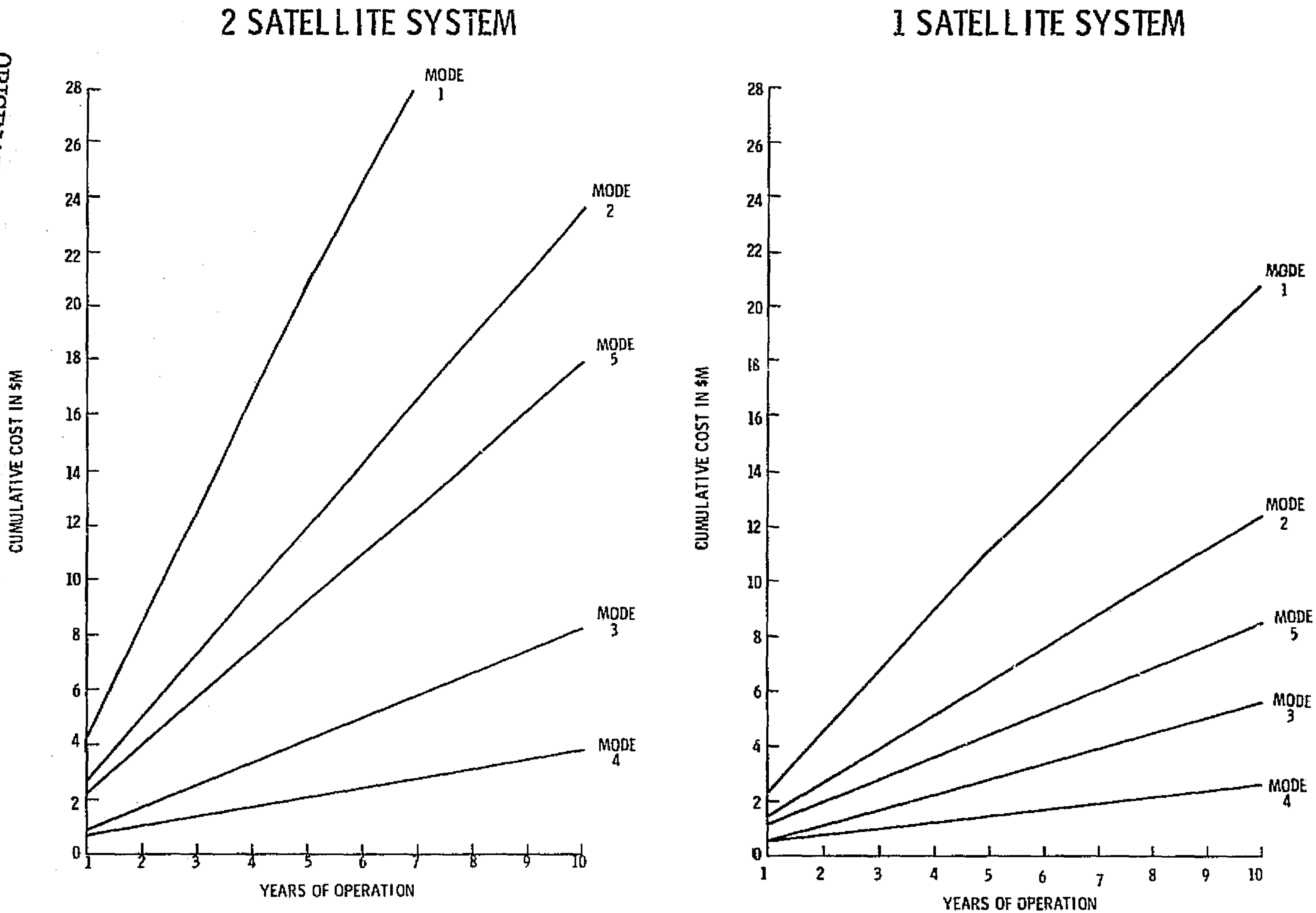
Mode 3 HDT_A data is permanently archived and used in conjunction with a HUL. This system provides no access to the raw data gathered (over 2/3 of the total data acquired is unavailable to the users) but does provide permanent availability of the selected "most useful" data (HDT_A).

Mode 4 Provides a one year archive of HDT_A data (backed up by a HUL). This is the absolute "bare bones" archive, allowing access to selected data for one year only. After this period, the data is unavailable unless stored by a user.

Mode 5 This is a version of Mode 2 with the permanent archive containing radiometrically corrected data. This results in a 1/3 data compression, thus lowering costs without decreasing the data content of Mode 2.

The cost of magnetic tape to implement the various modes is shown in Figure 4-1a(for a 2-satellite system) and in Figure 4-1b (for a 1-satellite system).

Mode 3 was selected for inclusion in the system since it provides good utility to users at minimum cost. Any lower archive content will eliminate the ability of users to perform historical data correlations and other temporal analyses.



(a) Two Satellite System

(b) One Satellite System

Figure 4-1. Cumulative Tape Archive Cost

SECTION 5

SITE SELECTION FOR THE LANDSAT D GROUND SYSTEM

5.1 INTRODUCTION

The four facilities constituting the Landsat D Ground System are the Data Input Subsystem (DIS), the Central Data Processing Facility (CDPF), the Product Generation and Dissemination Facility (PGDF) and the Operational Control Center (OCC). Preliminary tradeoffs established that the location of these four facilities has both operational and economic impact on the ground system. This section examines the site selection problem and provides both quantizable (cost) and qualitative (convenience, feasibility, etc.) results.

5.2 SITE SELECTION CRITERIA

It is recognized that not all site criteria can be evaluated quantitatively and that some qualitative criteria will be included in the tradeoffs. A system that is calculated to be a low cost option but which for "qualititative" reasons cannot be staffed adequately is not viable. The following criteria are believed to deserve consideration in this study.

a. Costs

-a-1. Initial Costs. This includes the costs of establishing the facility (buildings, land acquisition, support conveniences, personnel transfers and training, etc.).

a-2. Operating Costs. These costs involve the operation of the facilities (utilities, facility labor, expendables), transportation costs, management costs, etc.

b. Communications

This criteria involves both cost and operational convenience. It deals with the transfer of data and products between facilities and/or users.

c. Transportation

The availability of existing or nearby adequate transportation services is an important criteria. The transport of both personnel, materials and supplies should be considered.

d. Staffing

If at all feasible, only the key personnel should be "brought to the site". The remainder of the staff should be available from the local labor pool. This will require the local availability of a full spectrum of personnel from highly skilled to untrained.

e. Existing Facilities

It is highly desirable to avoid duplication of facilities or the abandonment of usable facilities; thus currently operational facilities that are functionally "integratable" into the ground system should be considered as site candidates. In addition, the proximity to certain existing facilities may be an advantage to the Landsat D ground system.

f. Community Conveniences

This criteria involves the desireability of the candidate site (for transfer of key personnel) and includes schools, housing, civic attitudes and public facilities (libraries, etc.).

g. Intangibles

There may be other driving functions involved in the suitability of a site. These may include political and socio-economic parameters, unwillingness to share facilities with other programs, etc.

5.3 CANDIDATE SITES

Three prime areas for consideration are immediately recognizable. These are White Sands, New Mexico; Sioux Falls, South Dakota; and the Washington, D. C. area. The alternatives, which consist of any other location in the U. S. A., shall be lumped in the heading of "others".

Initial rationale for candidate site nomination:

a. White Sands, New Mexico

The TDRSS Ground Station located at White Sands, New Mexico, is the main link between the Landsat-D satellite and its ground system. It would be an immediate logical choice for the location of the Landsat-D system, if there were no external constraints, existing facilities elsewhere, and interaction requirements with established facilities at other sites.

b. Sioux Falls, South Dakota

The location of the currently operating EROS Data Center, has demonstrated good suitability for a service facility. Good community interaction and support, the availability of reasonably priced manpower and a good operational record characterize this candidate site.

c. Washington D. C. Area

This candidate site is the location of the Landsat project office at GSFC, NASA Headquarters, NDPF and other facilities. It has an established labor pool of all levels of skills and is a major cultural center.

d. Others

In light of the preceeding three candidate sites, all others seem too pale (based on initial considerations). No other sites will be substantially more accessible, have better manpower availability, or have better proximity to Landsat D functional components. The tradeoff shall concentrate on the first three candidates.

5.3.1 Site Characteristics

The data required to evaluate each site against the criteria listed in Section 5.2 is summarized in Table 5-1. These data are qualitatively evaluated (positive or negative influence on site desirability) in Table 5-2.

5.3.2 Requirements

The general system requirement can be stated as:

- o minimize wide band data links and thus cost & complexity
- o minimize operating costs
- o maximize operational control and flexibility

These gross requirements should be considered as goals in site selection. The impact of existing capabilities (facilities and personnel) must also be evaluated, and the cost vs. operational utility (a value judgement) be established.

The ideal site would have:

- o adequate support facilities (power, water, etc.)
- o low acquisition costs
- o reasonable operating costs
- o attractive life style
- o no great extremes of climate or weather phenomena
- o adequate local manpower pool
- o good transportation and communications facilities

5.4 FACILITY SIZING

The space requirements for the various facilities are developed in this section. Where possible the space estimates are based on extrapolation of data from existing similar facilities.

Table 5-1. Candidate Site Characteristics

	WHITE SANDS	SIOUX FALLS	WASH., D.C. AREA
Nearest Population Center	Los Cruces 29,300	Sioux Falls 65,500	Wash., D.C. 764,000
Nearest Large City	(45 mi.) El Paso 277,000	Minneapolis - St. Paul (210 mi.) 797,000	(5 mi.) Wash., D.C.
Local Higher Education Facilities	New Mexico State Univ. Lib. Arts Engineering Engr. Tech. (2 yr.) 7400 students	Augustana College Lib. Arts Tech. Coops (2 yr.) 2100 students Dakota State College Lib. Arts Pre-Prof. (2 yr.) 1300 students	Howard University Engineering Medical Lib. Arts 12,200 students George Washington U. Engr. Medical Lib. Arts 13,200 students Univ. of Maryland Engr. Medical Lib. Arts/Science 46,700 students
Unemployment Situation*			
State	Substantial	Low	Concentrated
Local area	Substantial	Low	Concentrated
Existing Facilities (LFo Related)	TDRSS Ground Station (to be built by 1980) NASCOM/TDRSS I/F	EDC	NDPF Orbit Determination Group Landsat Program Office Landsat Project Office
Airline Connections	Poor to Los Cruces Excellent to El Paso	Good to Excellent	Excellent
Shipping	Major UPS	Through local transfer	Major direct route
Major Roads	I25, I10	I90, I29	I95, I270, I83

* Area trends in unemployment August - September, 1975, U.S. Dept. of Labor

Low - below national norm

Substantial - above national norm for total area being sampled

Concentrated - above national norm in portions of the area being sampled.

Table 5-1. (Cont)

		WHITE SANDS	SIOUX FALLS	WASH., D.C. AREA
Rain Fall/yr		5 - 7"	21 - 24"	14 - 38"
Snow Fall/yr		6 - 8"	40 - 48"	15 - 20"
Degree days		4500	7800	4200
Temperature	J	46	8	36
	F	52	19	37
	M	53	20	45
	A	63	48	56
	M	72	59	66
	J	79	61	75
	J	82	73	79
	A	81	73	77
	S	74	62	71
	O	59	43	60
	N	51	33	48
	D	48	19	37
Potential Weather Problems		some sand storms	tornadoes, flooding	high summer humidity some winter snow tie-ups
Equip. Service Centers	IBM	nearest center in Albuquerque (190 mi.)	Center in Sioux Falls	Centers in area
	Burr-oughs	Centers in White Sands, N.M. El Paso, Texas (45 mi.)	Center in Sioux Falls	Centers in area
	DEC	Centers in Alomogordo, N.M. (28 mi.)	Centers in Omaha, Neb. - (170 mi.); Minneapolis, Minn. - (250 mi.)	Centers in area
	HP	Center in Las Cruces, N.M. (28 mi.)	Center in St. Paul, Minn. (260 mi.)	Centers in area

Table 5-2. Site Characteristic Evaluations

	WHITE SANDS		SIOUX FALLS		WASH., D.C. AREA	
	+	-	+	-	+	-
COSTS	avg. Construction costs		avg. const costs			high const. costs
	low heating costs			high heating costs	low heating costs	
		avg. cooling costs	low cooling costs			avg. cooling costs
	low labor costs	Key personnel will have to be moved in.	low labor costs	Additional key personnel may have to be moved in.	Key personnel can be re-cruited in area.	relatively high labor costs
COMMUNICATIONS	Site of NASCOM TDRSS I/F			Requires wide band link w/ NASCOM		Requires Wb link w/NASCOM
	adequate telephone		adequate telephone			Adequate telephone.
TRANSPORTATION		major airport 45 miles away	major airport in city		major airport near city	
	near major interstates		near major interstates		near major interstates	
	major direct truck routes			no major di-rect truck rts	major direct truck routes	
STAFFING	Local univ. is potential source of skilled & pro-fessional labor			Local supply of skilled & pre-professional labor is low.	Large supply of skilled & professional labor in area.	
	high unemploy-ment area, should have large supply of un-skilled/trainable labor		area has proven good supply of unskilled/train-able labor			unskilled/trainable labor would tend to be in lower supply at higher cost than other areas

Table 5-2.(Cont.)

	WHITE SANDS		SIOUX FALLS		WASH., D.C. AREA	
	+	-	+	-	+	-
STAFFING (Cont.)		Key personnel from urban areas may be reluctant to move here.		Key personnel from urban areas may be reluctant to move here.	Identified as a regional cultural center.	
EXISTING FACILITIES		Remote from program office		Remote from program office; remote from data input facility		Remote from data input facility
COMMUNITY CONVENIENCES	large univ. in area		small lib. arts oriented colleges nearby		many major univ. & small colleges nearby	
	easy drive to El Paso			210 miles to nearest large city	is a major cultural center	
	housing costs average		housing costs relatively low			high housing costs
	consumer price index low		consumer price index avg.			consumer price index quite high
	moderate climate, low humidity	some hot spells in summer	moderate climate	cold winters, rapid temp. changes	generally mild climate	hot humid summers
SITE CAPABILITY	Area can absorb facility and probably needs economic uplift. Land at White Sands is government owned		Active Chamber of Commerce has made EDC very welcome. Would do same for any add'l facilities. Land can probably be obtained at low cost or community subsidized.		There is land and sufficient support capability available at GSFC.	NASA may not administer PGDF therefore, it may not want it on NASA property.

Table 5-2. (Cont.)

	WHITE SANDS		SIOUX FALLS		WASH., D.C. AREA	
	+	-	+	-	+	-
INTANGIBLES	High local unemployment may create pressure to locate maximum facility.		Strong political pressure not to obsolete EDC can be expected. COC will campaign at least for the PGDF Dept. of Interior has investment in area.		Project office may require that OCC be located in proximity.	

5.4.1 PGDF

The PGDF has a currently operating counterpart in the EROS Data Center (EDC). This center located in Sioux Falls, S.D, has 120,000 square feet of building space. Many of the functions/facilities performed at the EDC are similar to those required for the PGDF and include a User Service Office, Photo Lab, Photo archives, Data Management Group, dissemination facilities and support areas. The PGDF has additional requirements, mainly associated with the processing and archiving of digital data.

5.4.1.1 Estimates for Film Storage (Archive)

All "film" data will be stored on 9" rolls (with protective cans).

- Roll Specifications

roll capacity	250 images/roll
size of protective can	5 11/16 Dia. x 10 Long

- Storage Cabinet

  The storage cabinets for roll film archives are assumed to be similar to the configuration shown in Figure 5-1. This cabinet holds 84 rolls and requires 13.25 square feet of floor space (including access space).

- Space Calculation

  The peak loading expected is 438 frames per day, each frame consisting of 11 bands. Thus for ten years of operation 365 da/yr x 10 yr x 438 frames/day x 11 bands/frame x 1 image/band = 176×10^5 images/10 yrs.

$$175 \times 10^5 \text{ images/10 years} \times \frac{1 \text{ Roll}}{250 \text{ images}} \times \frac{1 \text{ Cabinet}}{84 \text{ Rolls}} \times 13.25 \text{ ft}^2\text{/cabinet}$$

$$= 11,105 \text{ ft}^2.$$

Thus about 11,000 ft^2 of space must be allocated for the film archive.

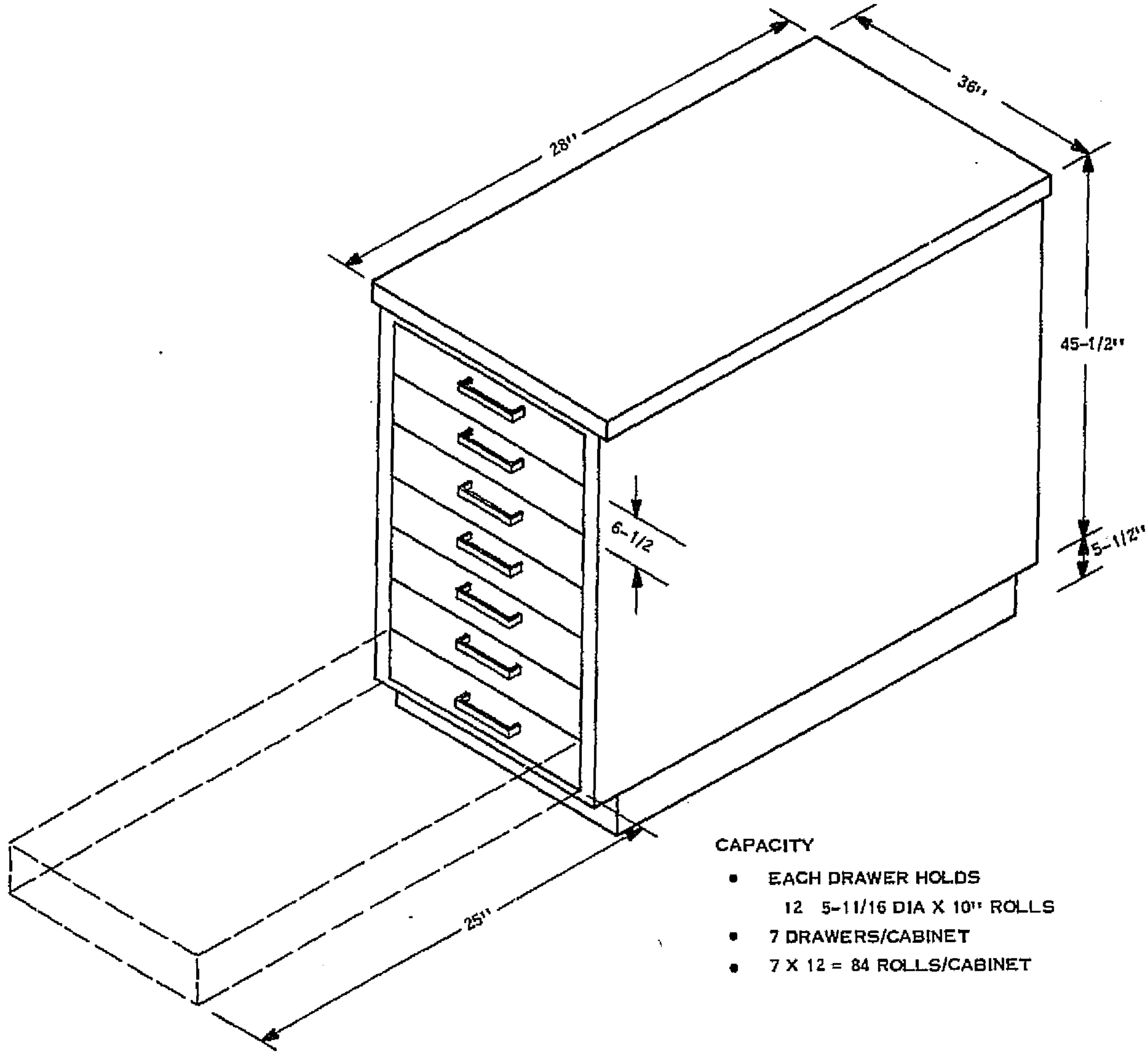


Figure 5-1. Archival Film Storage Cabinet

- Summary and Estimates

Film archive	11×10^3 ft^2
Raw film storage	2×10^3 ft^2
Photo Paper storage	2×10^3 ft^2
Flat storage	2×10^3 ft^2
Office and Work area	3×10^3 ft^2
Browse film storage	$.3 \times 10^3$ ft^2
Total	20.3×10^3 ft^2

5.4.1.2 Photolab Estimates

The Photolab at EDC occupies about 30,000 ft^2. This includes some archival and storage space. It is felt that, even with increased output requirements, this type of facility can handle the Landsat D demand. Thus a 30,000 ft^2 photo lab estimate appears valid.

5.4.1.3 Other Areas

The space requirements for general operational and functional areas required at the PGDF are shown in Table 5.3.

The total for these areas is estimated at 93.5×10^3 ft^2.

5.4.1.4 Digital Tape Archive Sizing

The digital data will be stored on 14" diameter reels of 1" tape. Figure 5-2 shows a typical arrangement for tape reel storage which stores 8 tapes per square foot.

- Tape Storage requirements

HDT_R

$$54 \frac{\text{reels}}{\text{day}} \times \frac{365 \text{ day}}{\text{year}} \times 10 \text{ yrs} \times \frac{1 \text{ ft}^2}{8 \text{ tapes}} = 24,637 \text{ ft}^2$$

HDT_A

$$9 \frac{\text{reels}}{\text{day}} \times \frac{365 \text{ day}}{\text{year}} \times 10 \text{ yrs} \times \frac{1 \text{ ft}^2}{8 \text{ tapes}} = 4,106 \text{ ft}^2$$

Table 5.3 Space Requirements for Operational and Functional Facilities of the PGDF

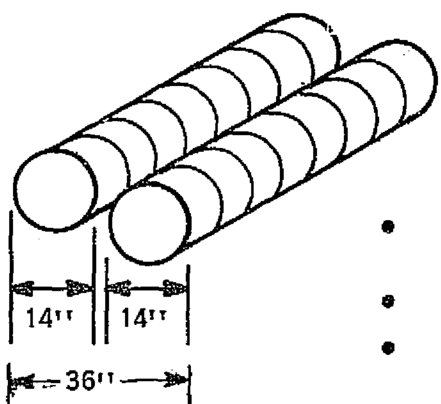
	$10^3 ft^2$
Cafeteria for 150 people	3.5
Sanitary 4 sets - 500 each male, 500 each female	4
Auditorium	2
User Rooms	2
Extractive Display (Image 100, etc.)	2
Lobby	1.3
User Office	7.5
Data request computer	3
Facilities (Boiler, A/C, etc.)	10
Mail Room	2
Loading Dock, etc.	4.5
Dissemination	3
Data Management Group	4
Storage areas (stationary, etc.)	2
Maintenance Shop	2
Management Offices & Conferences Rooms	2
Administrative Offices (acct., PR, etc.)	6
Personnel Offices	1.5
Nurse and medical	.7
Chem. mix and storage	1.5
Misc. Conference Rooms	2
Quality Control Rooms	.9
Plant Engineering	1
Purchasing	1.7
Spares, Storage & Vendor Maint. Areas	2.5
Tape Duplication	4
Reformatter	1

Table 5-3. (Continued)

Enhancer		.5
Film Recorder		1.3
Browse Generator		.5
Geom. correction		1.5
Reproduction		1.5
Misc.		2
Sub-total		83.5
Hallways & access in rear	10%	9.0
Total		93.5

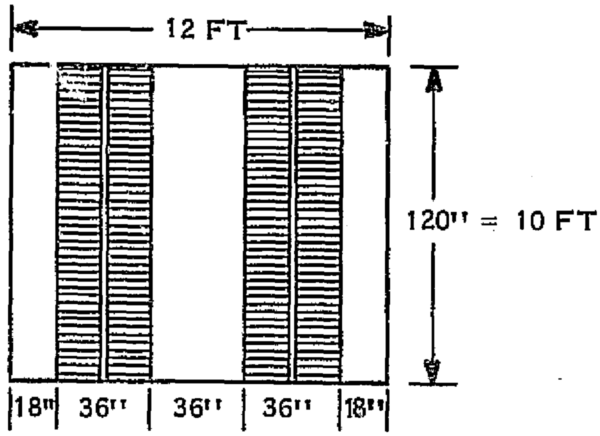
- Summary and totals (Digital tape archives)

HDT_R Storage	25.6×10^3 ft^2
HDT_A Storage	4.1×10^3 ft^2
Tape Recertify and Store	
1 month supply store	1.6×10^3 ft^2
reconditioning area	1.5×10^3 ft^2
Offices and work area	2.5×10^3 ft^2
Total	35.3×10^3 ft^2



- ASSUME 0.2 FT OF SHELF LENGTH REQUIRED PER TAPE CAN
- EFFECTIVE SHELF WIDTH IS 36"
- RACK IS 5 SHELVES HIGH

Figure 5-2a. Tape Reel Storage



$$\frac{1}{\text{SHELF}} \times 5\ \frac{\text{TAPES}}{\text{FOOT}} \times 40 \text{ FEET} \times 5 \text{ SHELVES} = 1000 \text{ TAPES}$$

$$1000 \text{ TAPES}\ \frac{1}{10 \text{ FT} \times 12 \text{ FT}} = 8.33 \text{ TAPES/FT}^2 \quad 8 \text{ TAPES/FT}^2$$

Figure 5.2-B Typical Shelving Layout Including Access Space

5.4.1.5 Total PGDF Space Requirements

The various subtotals of space requirements stated are considered conservative and probably on the low side. The gross aggregate is:

Film storage	20.3×10^3 ft^2
Photolab	30.0×10^3 ft^2
Ops & Funct. areas	93.5×10^3 ft^2
Digital tape arch.	35.3×10^3 ft^2
	179.1×10^3 ft^2

For purposes of estimating costs and to allow for future system growth we shall use 250×10^3 ft^2 as the gross aggregate space requirement associated with the PGDF. (The current EROS Data Center at Sioux Falls has 120×10^3 ft^2 and primarily handles film data).

5.4.2 CDPF

The space requirements for the CDPF are estimated at 15×10^3 ft^2. This is compatible with similar existing installations.

5.4.3 DIS

The DIS space requirements are estimated at 10 - 15 x 10^3 ft^2.

5.5 COST ANALYSIS

The impact of various locations on system implementation and operating costs are evaluated in this section. The analysis assumes that the operating payroll, the cost of expendibles, and services will be similar for all locations. This is reasonable since most of the staff are expected to be "graded" government employees, and the cost of supplies to the government is generally the same (regardless of geographic region) due to blanket pricing contracts.

5.5.1 ALTERNATIVES CONSIDERED

Any one, or all of the three major facilities (DIS, CDPF, PGDF) of the ground system can reasonably be located at the three designated (in Section 5.3) candidate sites. Since functionally the OCC should be accessible to the program office, it was decided to place it in the Washington, D.C., area.

One of the DIS's main functions is to interface with the NASCOM TDRSS facility at White Sands. White Sands is therefore the logical location for the DIS (all other locations will involve greater communications cost and greater operational complexity). Thus this analysis will assume that the DIS will be located at White Sands, New Mexico. The decisions for locating the PGDF and CDPF are not that obvious and require more analysis. Figure 5-3 shows four alternatives for facility locations. These will be evaluated to establish relative associated costs.

5.5.2 COST ANALYSIS

The costs used in this analysis are:

- Initial construction costs
- Building operating costs
- Site Management costs
- Data communication costs

These will be used to establish Δ costs for the four site alternatives.

	ALT. 1			ALT. 2			ALT. 3			ALT. 4		
	GSFC	SIOUX FALLS	WHITE SANDS	GSFC	SIOUX FALLS	WHITE SANDS	GSFC	SIOUX FALLS	WHITE SANDS	GSFC	SIOUX FALLS	WHITE SANDS
DATA INPUT SUBSYSTEM DIS			X			X			X			X
CENTRAL DATA PROCESSING FACILITY CDPF	X			X					X			X
PRODUCT GENERATION DISSEMINATION FACILITY PGDF		X		X				X				X
	SIMILAR TO CURRENT SYSTEM			CONCEN-TRATED AT GSFC			NO GSFC FACILITIES			ALL AT WHITE SANDS		

Figure 5-3. Site Selection Alternates

5.5.2.1 Initial Construction and Building Operating Costs

The cost of constructing various types of facilities is tabulated in "Building Construction Costs Data, 1975" published by MEANS Co., Inc. Figure 5-4a shows the data relevant to the Landsat D Ground System facilities. The cost associated with an "Industrial R&D Facility" are believed to reflect the requirement for the PGDF and CDPF adequately. The data shows that this type of facility will have a construction cost (not including site acquisition) of $\$40.80/ft^2$. The cost of materials and labor vary rather widely depending on the geographic area. Figure 5-4b shows the relative indices, both labor and materials, for the candidate sites. The cost factor when multiplied by this regional index provides a reasonably good estimate for construction at the candidate site. For example, the cost of constructing the PGDF (250,000 ft^2) in the Washington, D.C., area is:

$$250{,}000\ ft^2 \times \$40.80/ft^2 \times .99 = \$10.2 \times 10^6$$

Similar calculations yield the data for Sioux Falls and White Sands. The results are shown in Figure 5-4c.

5.5.2.2 Building Operating Costs

The principal annual cost of maintaining a building consists of the staff payroll, cost of expendables, taxes and amortization. Since the facilities will be government-owned the tax item can be eliminated. For the sake of simplification, amoritization will not be considered (it is a fractional portion of the initial cost which is used in the tradeoffs).

GE experience has shown that the annual operating cost of an industrial R&D facility (excluding taxes and amortization) is $\$7/ft^2$. This breaks down further into $\$3/ft^2$ in materials and $\$4/ft^2$ in labor. Using the labor index from Figure 5-4b we can calculate the estimated annual operating costs for the PGDF located in White Sands, New Mexico, as:

$$(250{,}000\ ft^2)\ (\frac{\$3/Yr}{ft^2} + \frac{\$4/Yr}{ft^2} \times .66) = \$1.41\ \ 10^6/Yr$$

Similar calculations provided the annual operating cost figures tabulated in Figure 5.4c.

FACILITY TYPE	$ COST PER FT^2
COLLEGE R&D LABS	45.90
HOSPITALS	53.10
LIBRARIES	38.45
INDUSTRIAL R&D	40.80
OFFICES	32.85

CITY	RELATIVE COST INDEX		
	MAT'L	LABOR	TOTAL
EL PASO TX	98	66	80
SIOUX FALL SD	101	85	92
WASHINGTON D.C.	100	99	99

*SOURCE - BUILDING CONSTRUCTION COST DATA - 1975 MEANS CO INC.

$$250,000 \times 40.80 \times .99 = 10.2 \times 10^6$$

FACILITY COSTS		EFFECTIVE COSTS IN MILLION $					
BUILDING OPERATION ANNUAL LABOR	$4.00/SQ. FT.	WASHINGTON D.C.		SIOUX FALLS S.D.		WHITE SANDS N.M.	
ANNUAL SERV & MATERIALS	$3.00/SQ. FT.	CONST	ANNUAL OPER.	CONST	ANNUAL OPER.	CONST	ANNUAL OPER.
PGDF (250,000 SQ. FT.)		10.2	1.74	9.4	1.60	8.1	1.41
CDPF (15,000 SQ. FT.)		.6	.104	.56	.096	.49	.085

BUILDING OPERATION ANNUAL LABOR

ANNUAL SERVICE & MATERIALS (CONSTANT)

$$250,000\,((3.00 + 4.00\,(.66)) = 1.41 \times 10^6$$

Figure 5-4. Site Selection Facility Costs

5.5.2.3 Site Management Costs

It is recognized that program office management personnel will have to interface with the various facilities. The home base for these personnel is GSFC; thus facilities located in the Washington, D.C. area will have the lowest cost (negligible) associated with interface management. The data in Figure 5-5 shows the estimated number of management trips (at $1,000 each) required for interface management at various site alternatives. The costs (recurrent) are also tabulated.

In addition to the above, the cost of transferring key personnel to a site must be considered. Industry figures show that a key man transfer cost is on the average, $10,000. If we consider GSFC the home base and adopt the groundrule that every facility remote from GSFC will require the transfer of 10 key people (at $10,000 per person) we derive the data shown as non-recurring costs in Figure 5-5.

5.5.2.4 Data Communication Costs

The various facilities of the Landsat D Ground System transfer data by means of High Density Digital Tapes if in close proximity or by means of DOMSAT links (if remotely located). The inputs and outputs of the DOMSAT links are also High Density Digital tapes. Figure 5-6 shows the equipment, High Density Digital Recorders (HDTR), DOMSAT Transmitters and Receivers and DOMSAT Transponders required with each of the site alternatives. The high cost of leasing the DOMSAT equipment and purchasing the HDTR's indicates that these costs may be the chief driving function in the site selection process. The cost differences for the various alternatives are tabulated, in Figure 5-6 (Alternative 4, the lowest cost alternative, was selected as a basis for comparison).

5.5.2.5 Cost Summary

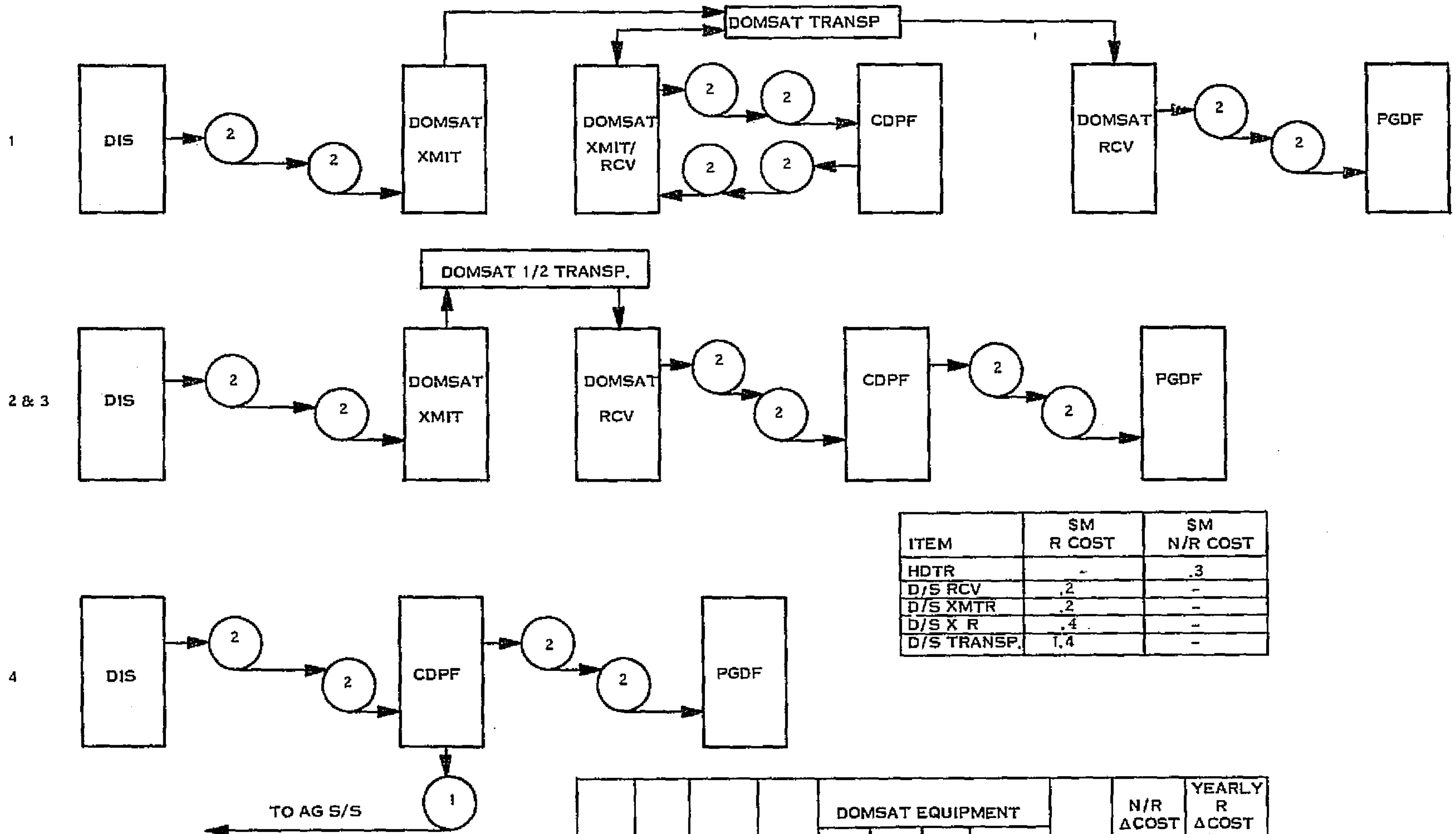
The various nonrecurring and recurring cost deltas (Δ), derived in Section 5.5 for each alternative, contributed to a total Δ cost (from Alternative 4). The cumulative system Δ costs for 5 and 10 years are shown in Table 5-3. The data in this table shows that the location of the facilities has a substantial impact on system operational costs. The potential saving in operating costs (over 10 years) of locating all ground system facilities at White Sands, New Mexico, (as opposed to the PGDF at Sioux Falls and the CDPF at GSFC) is conservatively 27.2 million dollars. This number does not factor in the lower heating and cooling costs associated with the more even temperature climate at White Sands.

ALT	DIS	CDPF	PGDF	NO. KEY PEOPLE MOVED	NO. OF ANNUAL I/F MGMT. TRIPS	N/R COST $M	R COST $M
1	WS	GSFC	SF	0	60	0	0.06
2	WS	GSFC	GSFC	10 (TO GSFC)	0	0.1	0
3	WS	WS	SF	10 (TO W.S.)	120	0.1	0.120
4	WS	WS	WS	20 (TO W.S.)	80	0.2	0.80

COST OF KEY MAN MOVE $ 10,000 EA. (TYPICAL INDUSTRY COST OF INTERCITY MOVES)

COST OF MANAGEMENT TRIP 1,000 EA.

Figure 5-5. Facility/Management Interface Costs



ITEM	$M R COST	$M N/R COST
HDTR	-	.3
D/S RCV	.2	-
D/S XMTR	.2	-
D/S X R	.4	-
D/S TRANSP.	1.4	-

ALT	DIS	CDPF	PGDF	DOMSAT EQUIPMENT XMIT	REV	X/R	TRANSP	HDTR	N/R ΔCOST $M	YEARLY R ΔCOST $M
1	WS	GSFC	SF	1	1	1	1	16	2.1	2.2
2		GSFC	GSFC	1	1		1/2	12	.9	1.1
3		WS	SF	1	1		1/2	12	.9	1.1
4		WS	WS					9	0	0

Figure 5-6. Site Selection Communications Costs

Table 5-3. Cost Summary

Alternative	ANNUAL RECURRING COST Δs ($10^6) Δ Domsat Equip.	Δ Building Maint.	Δ I/F Mgmt. Trips	Total Recurrent Cost Δ	NON-RECURRING COST Δs ($ 10^6) Δ Const. Cost	Δ Comm. Equip.	Δ Personnel Transfer	Total Non-Recurring Cost Δ	ΣΔ 5 YRS. ($10^6)	Σ 10 YRS ($10^6)
1	2.2	.019 .19 .209 .209	- .02	2.389	.11 1.3 1.41 1.41	2.1	- .2	3.31	15.26	27.20
2	1.1	.019 .330 .349 .349	- .08	1.369	.11 2.10 2.21 2.21	.9	- .1	3.01	9.86	16.70
3	1.1	.000 .19 .19 .19	.04	1.33	.00 1.3 1.3 1.3	.9	- .1	2.1	8.75	15.40
4	0	0	0	0	0	0	0	0	0	0

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5.6 SUMMARY

The cost analysis shows the advantages of colocating all facilities (PGDF, CDPF and DIS) at White Sands, New Mexico. This facility is near several major military installations, a major university, and has good community, transportation and communication facilities. (See Tables 1 and 2). It will house the sophisticated TDRSS ground system and the associated technical support personnel and facilities. It is, by all criteria, (See Section 3) a viable site with full capability to support the Landsat D ground system.

An added set of technical and functional advantages accrue in the system due to the co-location of facilities. These are listed in Table 5-4. Thus, all indications are that a colocated set of facilities is cost effective and efficient and that colocation at White Sands, New Mexico is the most cost effective and system efficient site for the Landsat D ground system.

Table 5-4. Site Selection Additional Considerations

- CO-LOCATION
  - EQUIPMENT SHARING AT WHITE SANDS MINIMIZES HARDWARE
  - SIMPLIFIES SYSTEM DESIGN AND SUB-SYSTEM INTERFACES

ELIMINATES

- 2 LOCAL SITE DATA MGMT. COMM. TERMINALS
- 4 HIGH DENSITY DIGITAL TAPE RECORDERS
- LEASED LINES FOR DATA MGMT. & CONTROL

SHARING

- TAPE RECERTIFICATION/CONDITIONING FACILITY
- LOGISTICS STORAGE
- COMPLEX EQUIPMENT SUPPORT PERSONNEL
- MGMT. AND SUPV. PERSONNEL
- DATA MGMT. COMPUTER

SIMPLIFIES

- DATA TRANSFER AND MGMT.
- STAFFING AND TRAINING
- SCHEDULING
- ADMINISTRATIVE FUNCTIONS